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Shipboard electrical consumption profile analysis

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THESIS

SHIPBOARD ELECTRICAL CONSUMPTION PROFILE ANALYSIS

by

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Shipboard Electrical Consumption Profile Analysis

by

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Submitted in partial fulfillment of the
requirements for the degree of

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ABSTRACT

Department of Navy energy consumption reduction goals have been established for afloat commands and shore installations in order to keep pace with the ever increasing demand and high cost of energy resources. This study examines electrical power consumption data for various Pacific Fleet ships berthed at Naval Station, San Diego, CA. during the period 1 Jan. 1990 - 19 Jun. 1991, in an effort to construct daily ship consumption profiles from averaged data. These daily profiles are compared for ships of the same class by means of graphical and statistical analysis in order to determine how well daily class profiles will be able to accurately estimate consumption and subsequent costs. Utility savings examples are also discussed with use of these profiles. Class and individual ship daily profiles are constructed from the analysis for the purpose of being useful as a budget forecasting tool for the U.S. Pacific Fleet Comptroller and also as means to examine ways to efficiently use electricity in the future.

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I. INTRODUCTION

A. BACKGROUND

Department of the Navy energy consumption reduction goals have been established for afloat commands and shore installations in order to keep pace with the ever increasing demand and high cost of energy resources. In particular, Naval Station, San Diego, CA., (NAVSTA S.D.) which is homeport for several Third Fleet ships as well as a major ship repair/maintenance facility, has recently joined with the Navy Public Works Center (PWC) Utilities Department, San Diego to invest in energy conservation measures. One of these initiatives involves PWC, San Diego as the designated lead agency to oversee the installation of time-of-use monitoring equipment to monitor electrical consumption of selected Naval Station buildings as well as ships berthed pierside at the Naval Station.

This real-time electrical metering system is currently providing electrical consumption data, sampled every fifteen minutes, in the form of electrical current and power demand, for ships berthed at piers 2 and 13. The system is able to provide separate data for up to four different berth locations on each pier.

The metering system hardware for pier 2 was installed by the Navy Civil Engineering Laboratory, Port Hueneme, CA. (NCEL) while the metering system hardware for pier 13 was installed by Honeywell, Incorporated. Both systems are designed to acquire the instantaneous (current, watts, power-factor) and accumulated (watt-hour) shipboard electrical usage every fifteen minutes and send the readings to the Honeywell host computer processing unit located at the PWC Utilities Engineering building. [Ref. 1]

PWC, San Diego acts as a utility company which operates and maintains the electrical distribution systems on the San Diego Navy bases and pays San Diego Gas & Electric (SDG&E) for the area Navy electricity usage. In turn, PWC charges its San Diego area Navy "customers" for their respective usage. These "customers" include the CINCPACFLT Comptroller for its San Diego based and other visiting Pacific Fleet ships.

Presently, since insufficient metering equipment precludes actual ship-by-ship electrical billing on all NAVSTA S.D. piers, PWC accountants rely on estimated ship electrical usage, apportioned by the main electrical meters supplying the piers to determine the electric bill for the CINCPACFLT Comptroller. The Pacific Fleet Comptroller has

no means to validate the electric bill received from PWC, which can be as high as $2 million per monthly billing period during the Summer months. It can easily be seen that if Pacific ships embarked on an in-port energy conservation program, the above mentioned accounting procedure used for billing may no longer be a fair assumption due to increased shipboard energy conservation awareness. Thus, PWC hopes that the additional electrical metering equipment, once installed, will eventually serve as an accurate means of billing their customers.

Third Fleet ships will be affected by the complete metering since the capability will exist to calculate individual ship electric bills. Briefly, the kilowatt-hour data for each ship will be multiplied by the energy charge rate, which depends on the time-of-use period for the particular day and season (see Figure 1) to yield an electric bill for each day the ship is in port receiving electricity from shore. There are three different energy charge rates per season (Winter and Summer) for a total of six rates per year.[1] The most recent PWC established rates which were applied to the profile analysis included:

1. OFF-PEAK: $ 0.05517 per Kilowatt-Hour (Summer)
2. SEMI-PEAK: $ 0.07424 per Kilowatt-Hour (Summer)
3. ON-PEAK: $ 0.11275 per Kilowatt-Hour (Summer)
4. OFF-PEAK: $ 0.05242 per Kilowatt-Hour (Winter)
5. SEMI-PEAK: $ 0.06349 per Kilowatt-Hour (Winter)
6. ON-PEAK: $ 0.10125 per Kilowatt-Hour (Winter)

One can observe from comparison of the time spans for the two on-peak periods in Figure 1, that the greatest potential for energy savings exists in the Summer months. In light of this and a shrinking operational budget, the CINCPACFLT Comptroller has expressed the need for finding a means to accurately track, forecast and conserve in-port energy usage.

B. OBJECTIVES

The purpose of this research project is to:

- Provide the CINCPACFLT Comptroller with a utilities budget forecasting tool in the form of graphical and numerical analyses for various U.S. Pacific Fleet ship classes.

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1 The ships will also be billed for demand in the form of surcharges which are referred to as coincidental and non-coincidental surcharges. The application of these charges are beyond the scope of this study, but their general effects on the electric bill are discussed in Section IV.

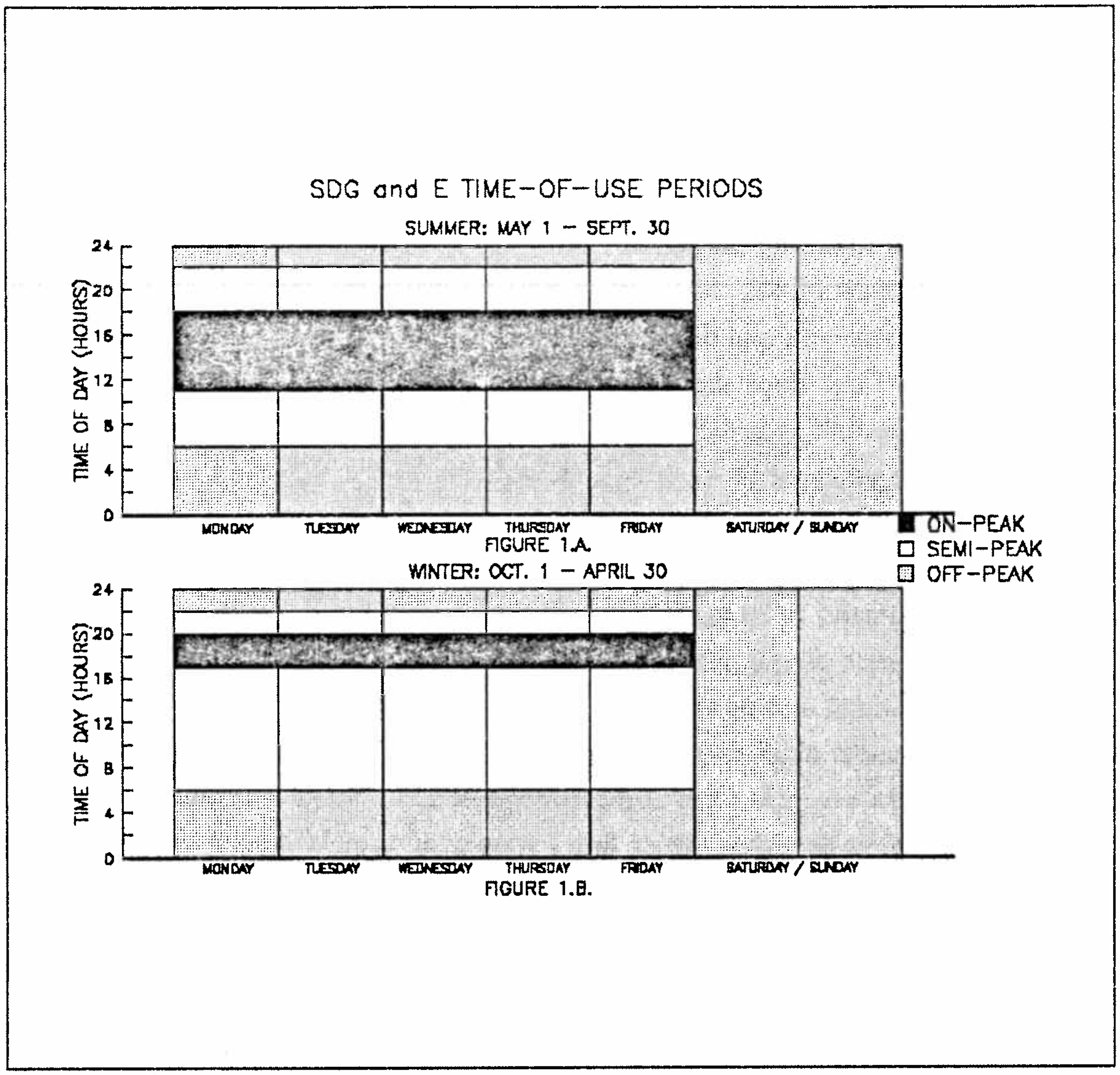

Figure 1. Time of Use Periods for Electrical Consumption: note that the On-Peak period represents the most expensive time to consume electricity.

- Provide the Fleet with representative in-port electrical usage profiles for different ship classes, thus allowing individual ship commanders to gauge their own electrical consumption against the respective class usage profile.
- Provide PWC, San Diego a summary list of problems encountered while performing the data analysis.

II. NATURE OF PROBLEM

A. DESCRIPTION OF DATA

Shipboard electrical consumption data was collected for 26 ships berthed at Naval Station piers 2 and 13 during the period 1 Jan. 1990 - 19 Jun. 1991. Despite having only two piers to collect data from, the length of time for which the data was collected along with the numerous arrivals and departures of different classes of ships provided a cross-section of typical Fleet ships that receive shore electrical power. A list of ships that participated in the study is provided in Appendix A, Table 1. The information in the table provides the reader with a better understanding of the classes of ships and their length of stay in port. Since these classes of ships are also found at the other remaining NAVSTA piers, the development of ship class energy consumption profiles would allow for utility cost estimates to be made for every pier.

For the purposes of this project, data in the form of current (amperage), power (watts and watt-hours) and power-factor were available. While the trends for current and power are analogous as energy demand increases or decreases, power in the form of watt-hours is the accepted form of measuring electricity usage that utility companies use to charge their customers. Each ship's watt-hour data, averaged over a specific billing period for each day of the week will be computed. A ship's daily energy consumption profile will consist of these averaged watt-hour data points. The averaged data will then be multiplied by the applicable electrical rate charge(s) which corresponds to the three different time-of-use periods depicted in Figure 1. The result represents the expected electric bill for each ship within the respective ship class for the specified billing period. The accompanying graphical results will include data smoothing techniques overlayed on the averaged data points. The graphical analyses will allow Fleet budget planners and shipboard managers to observe daily usage trends, especially during the on-peak period when energy rates are highest.

Due to the large magnitude of watt-hour usage for all Navy ships, the units are scaled in kilowatt-hours (Honeywell, pier 13) and megawatt-hours (NCEL, pier 2). Since the established charge rates (on-peak, semi-peak and off-peak) for electrical consumption are in $/kilowatt-hour, the pier 2 power data was converted to kilowatt-hours. Another reason for this conversion was to maintain a common unit of measure for the ***Y-axis*** (time versus ***electrical consumption***) when conducting a graphical analysis. Since

the megawatt-hour readings at pier 2 (NCEL) are designed to display only two significant digits, the applied conversion factor produces a power result that is accurate to the tens position. This will in turn result in perhaps a lower than expected standard deviation for the respective days averaged mean data points, whereas the kilowatt-hour readings at pier 13 (Honeywell) are accurate to the second decimal place. The differences in standard deviations about the mean data points do not pose a problem of comparison between like ships since ships in the same class used the same pier. Pier 2 received destroyers, frigates and the newest class of cruisers while pier 13 received amphibious class ships and the older classes of cruisers and destroyers.

The amount of data collected for individual ships at piers 2 and 13 depended on the duration of the ship's electrical shore power connection. Pending operational and maintenance requirements would often determine the ship's length of stay in port. Ships which had a long, uninterrupted shore power connection for a billing period were ideal for developing representative in-port electrical usage profiles. A list of billing periods is provided in Appendix A, Table 2. Basically, each billing period is a four to five week period that starts and ends at mid-month. Thus, a ship which has been in port for an entire billing period will have about four different sets of data readings for each day of the week (Monday - Sunday).

Since the energy consumption profiles were based on *averaged* kilo (or mega, as applicable) watt-hour data, those ships which received continuous electrical shore power throughout an entire billing period provided the most useful data to analyze. A minimum of two weeks in-port for a particular ship was required in order to calculate the average kilowatt- hour (KWH) data points for each day (an average of at least 2 data points for each day). Energy consumption by ships that were in port for very short periods of time (e.g., 24-72 hours) was extremely variable, probably due to propulsion plant machinery and radars still operating in anticipation of getting underway. It was decided that this type of data was not representative of *typical* usage to enter into class profiles. Thus, data collected in the latter case were not used in the profile development. However, since ship activity for the period observed also involved several short pierside visits (1 - 2 weeks), the resulting data sets for a particular ship within a billing period were averaged together. Situations also existed where a particular ship's short length of stay spanned adjoining billing periods. For example, the USS MERRILL was in port at pier 2 from May 8 to June 6, 1990. Using Table 2 (Appendix A), it can be shown that this data spanned billing periods 5 and 6. The number of days in port were sufficient for calculating daily average KWH values across the two periods, but not for each billing

period separately. Thus, in this type of situation, data from the two periods was combined (referred to as *merged* in the following related figures).

B. ORGANIZATION OF DATA

The IBM-built computer language APL2 and accompanying graphics language GRAFSTAT were utilized to organize, verify and summarize the data as well as to apply statistical and graphical techniques. These data readings for each day were organized into three separate columns: amperage, watts, watt-hours. Each column has ninety-six rows (4 fifteen minute intervals per hour x 24 hours per day). Once data sets for ships of interest were organized by daily electrical consumption, the watt-hours of each daily data set was examined to check for system output malfunctions that could in turn lead to unrealistic (high or low) power readings. A listing of the most common system malfunctions found and details concerning required phase angle conversion adjustments are provided in Appendix B.

A ship's workload will vary depending largely on its operational schedule and equipment repairs. For example, shipboard demand for power on July 3 (Tue.) during the hours 1 - 4 p.m. may vary from demand on July 17 (Tue.) during the same time period. Thus, joining as many columns of watt-hour readings as feasibly possible aims to capture the ship's flexing work load and subsequently provide the most *representative averaged* watt-hour values. Appendix B also provides a typical watt-hour data set and detailed reasoning for joining these sets of data.

The data gathering system at both piers was prone to relaying occasional erroneous data points to the host computer. Appendix B addresses the most common cases of watt-hour data errors. Whenever possible, the watt-hour data in error was corrected. These data errors were easily identified as outliers through the use of scatter plots. In cases where erroneous data could not be corrected, the points were deleted so as not to adversely influence the computed averaged values.

An APL2 function was used to compute, across the rows, the mean and standard deviation for each fifteen-minute interval of the watt-hour data sets. A scatter plot was then utilized to plot the mean values. Seven different scatter plots (Monday-Sunday) were completed for each ship which contained sufficient data to be averaged within a billing period. Scatter plots covering the seven day week served as a tool for determining an adequate y-axis range for the ships. Figure 2 shows the electrical consumption profile comparison between a modern era Spruance class destroyer (USS O'BRIEN) that was berthed at pier 2, receiving electrical shore power during billing period 7 (June 20- July

19, 1990) and a post-Korean war era Amphibious Tank Landing ship (USS PEORIA) that was berthed at pier 13, receiving electrical shore power during the same billing period.

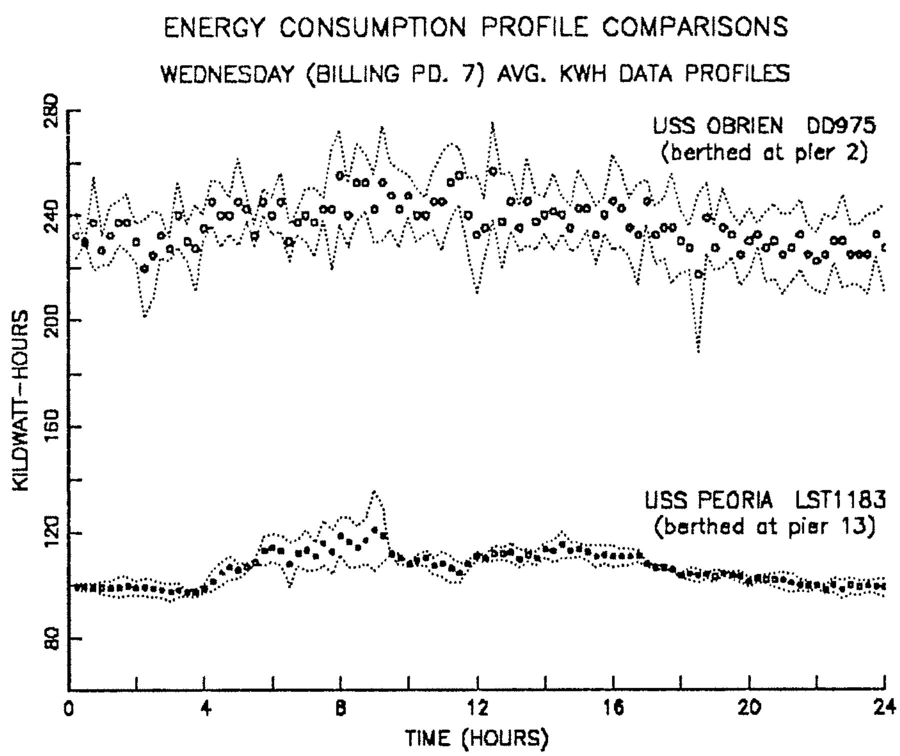

Figure 2. Electrical Consumption Profile Comparisons: the dotted lines are defined by the average plus and minus one standard deviation.

The above figure as well as the remaining graphs have been corrected for known data errors. The profile for USS PEORIA was constructed from three weeks of data, while the USS O'BRIEN's profile was derived from four weeks of data.

The large disparity in consumption levels and standard deviation ranges between the two ships is most evident. The reasons for these differentials are believed to be mainly due to the difference in age and mission of the two ships. For example, the USS PEORIA was commissioned in Feb. 1970 and does not contain a large amount of sophisticated electric-driven equipment which modern ships now possess. On the other hand, the USS O'BRIEN was commissioned in Dec. 1979 and consists of a relatively extensive amount of electric-driven equipment. With the addition of computer aided weapons and communications equipment, more air conditioning (A/C) units must also be installed onboard these modern-era ships. Newer ships, such as the latter, perform routine maintenance checks on their equipment which involve repeated on/off practices. It is also worth mentioning here that typical crew complement for the USS O'BRIEN is about 350 while the USS PEORIA has a typical crew size of about 230. The standard in-port displacement for both ships is about the same (8000 tons).

As seen in Figure 2, the average usage by USS O'BRIEN is more than twice that of USS PEORIA, and the highest and lowest standard deviations for USS O'BRIEN during the typical working hours (7 a.m. - 4 p.m.) were sixty-seven and two-hundred percent higher, respectively, than that of the USS PEORIA. Notice that for the USS PEORIA, a band of relatively large standard deviation values exists between times 5:45 a.m. - 9:15 a.m. The mean values are also steadily increasing during this period and then decline as the lunch break approaches. Afterwards, mean values rise again to a high level until 4:45 p.m.

One can also observe from Figure 2 that unique y-axis scales can be created for each ship class. After numerous scatter plot experiments with different y-axis scales for various ships, a y-axis range of 90 KWHs was chosen. This range was used for all ships, regardless of ship type or pier location, so that graphical analyses of demand patterns and side-by-side ship comparisons could be easily made. Appendix B discusses in detail the problems encountered in analyzing profiles which use large y-axis scales.

III. INVESTIGATION

A. GRAPHICAL COMPARISONS

Smoothing techniques were used with the power consumption data to explore the power demand behaviors that exist for ships throughout the course of a day. Previous Navy studies concerning in-port energy conservation have subscribed to the idea of using one overall average KWH value for each ship class [Ref. 2: p. B-2]. Graphical comparisons of smoothed power usage allow easy examination of season to season, day to day and within day consumption. Representative shipboard energy profiles can be useful for both the ship commanders as well as budget planners in order to obtain an accurate look at typical consumption levels.

After experimenting with various smoothing techniques, spline smoothing provided the best weekday profile curves employing cubic polynomials. The spline technique was preferred over other methods since data point trends, as illustrated in Figure 2, were not overshadowed by the smooth curve. Straight line averaging was found to be adequate for weekend days due to the steady consumption levels throughout the day.

The cubic smoothing spline gives the smoothest possible curve in terms of the integral of the squared second derivative and concurrently minimizing the error sum of squares (sum of squared residuals, differences between actual and fitted curve values). GRAFSTAT provides a cubic smoothing spline function which uses the input parameter P (the roughness penalty factor which can vary between 0 and 1), in order to track "average" usage. The spline function produces an estimator (the fitted curve) which fits the data well, but at the same time, has some degree of smoothness. When P is set to 0, the cubic smoothing spline will produce a curve which goes through every data point and result in zero residuals. The total cost computed from this rough curve exactly matches the total cost based on the plotted average data values, but is too detailed to be useful to the budget forecaster. When P is set close to 1, smoothness is emphasized and a heavy penalty placed on the estimators with large second derivatives. [Ref. 3: p. 189] The resulting spline will tend to resemble a straight line and produce large residuals for those days which have varying consumption levels.

Figures 3 and 4 demonstrate the application and effects of spline curve and average line smoothing for USS PEORIA and USS O'BRIEN. The previously mentioned Summer charge rates were used for both ships.

For the USS PEORIA, the Monday through Friday profile curves were best represented with P set to .5. Wednesday was observed to be the busiest work day. Figure 3 displays the small differences achieved in cost estimating and the relative tight fit of the chosen spline curve for the Wednesday consumption profile. From this profile, the forecaster and ship commander can see that demand is expected to be virtually stable at 100 KWH from 00:15 a.m. until 4 a.m. The weekend consumption levels were found to be generally stable throughout the entire day with small variations. Additionally, since there is only one charge rate for Saturday and Sunday (see Figure 1) and therefore no critical demand time periods, simply using the daily average was deemed adequate. Another observation that supports the use of straight line averaging is that the largest residual in the Saturday profile is less than three percent of the overall mean daily usage.

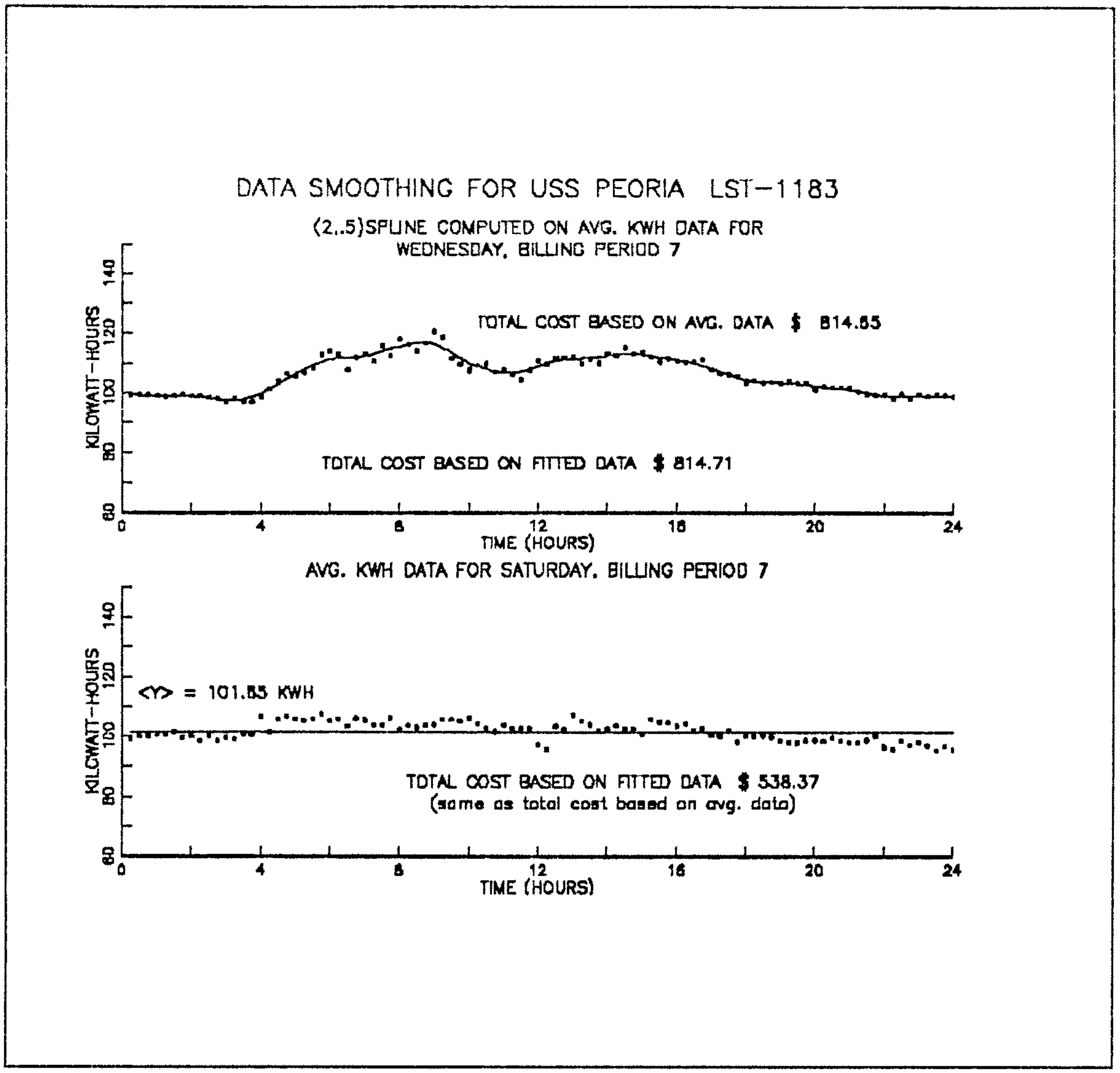

Figure 3. Power Consumption Profile Smoothing for the USS PEORIA LST-1183

For the USS O'BRIEN, the decision to set P=.8 for the weekday spline smoothing curves came after experimentation with several other P values. Once again, Wednesday was observed to be the busiest workday. The spline curve depicted in Figure 4 allows the ship commander to observe the two largest usage periods occurring just to the left and right of data point 40 (10 a.m.). Hence, energy conserving objectives might include reducing energy demand that occurs after 11 a.m. (start of Summer on-peak period) or a shift of some of the demand for electricity to the left of 11 a.m. The average plot was again used for the weekend days.

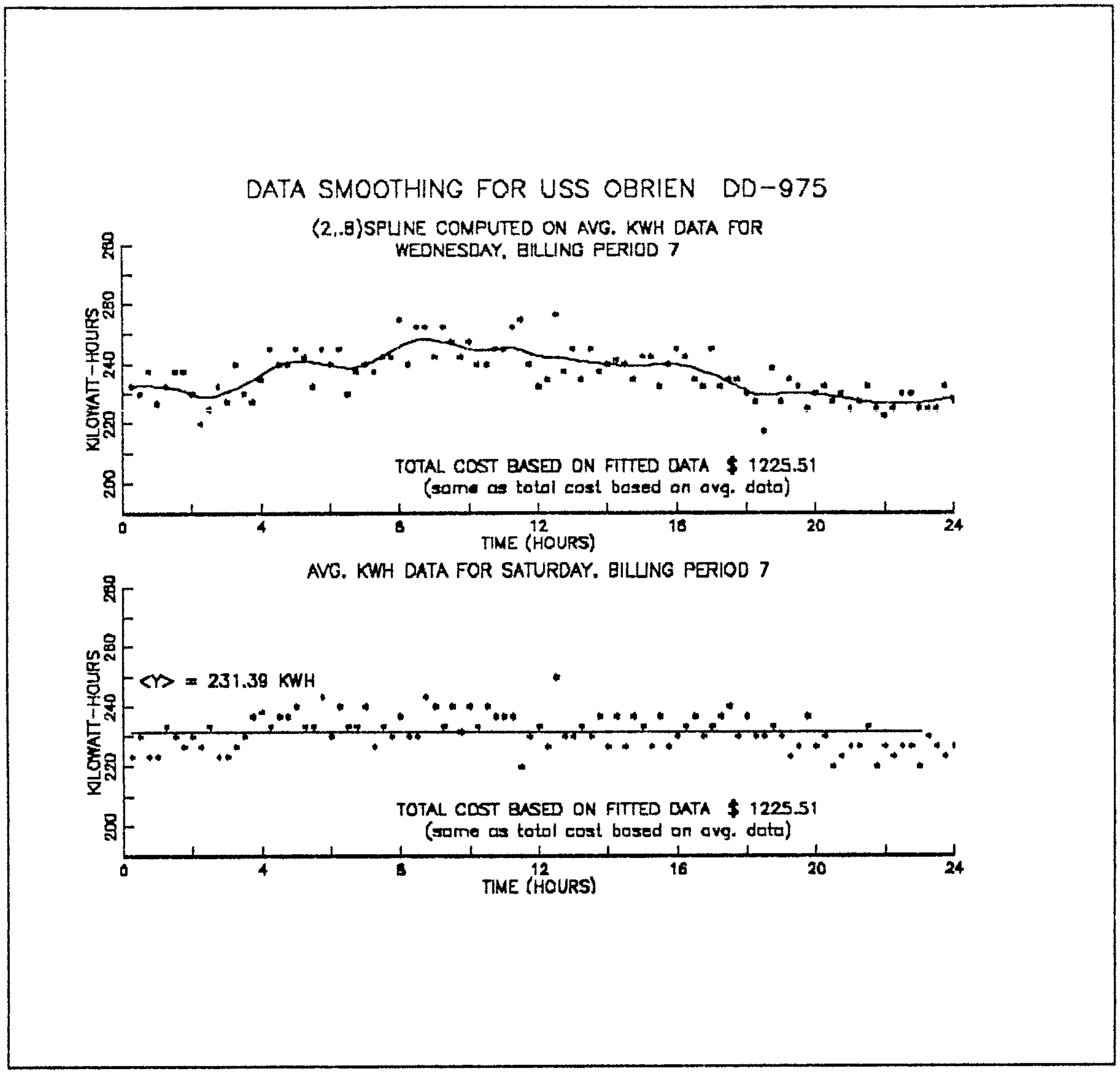

Figure 4. Power Consumption Profile Smoothing for the USS O'BRIEN DD-975

Since the scatter plot of averaged data points for USS PEORIA was considerably less erratic than that of the USS O'BRIEN, the spline curve selected for the former ship provided a tighter fit. These tight fitting curves prevailed primarily in these older ships, regardless of ship displacement increases.

1. Class Analyses

The idea of comparing profile curves of several ships from the same class and determining whether to create a set of representative class profiles (Monday-Sunday) was pursued with limited success. Spline curves and average lines were used to compare

average KWH consumption profiles of similar days of the week among a selected number of ships within the same class. Ships within the same class have very little differences in type and amount of major electrical powered machinery and equipment, however, the: (1) operational schedule of ships (e.g., preparing for a major deployment versus routine maintenance); (2) differences in manning levels (e.g., holiday leave periods, crew standdown after completion of major deployment, etc.); and (3) geographical differences in port locations, seemed to be some of the important factors which might explain differing levels of consumption. Questionnaires were distributed to each of the participating ships in an effort to understand and perhaps apply the first two mentioned factors to the class analyses, however insufficient replies precluded their use. The last factor mentioned is not explored in this study since all data collected was from NAVSTA, San Diego.

The following graphs compare selected ships from three different classes. It was assumed that one ship's profile in a particular billing period could be compared to a sister ship's profile from either the same, preceding, or following billing period since the climate in San Diego remained generally the same from month to month. However, extreme high temperatures will have an impact on shipboard energy usage due to the extra amount of A/C units required to cool internal work spaces which suggests that Winter and Summer demand levels may vary considerably.

In addition to comparing smoothing curves for each of the class comparison analyses (Figures 5 through 14), total daily consumption costs of each ship for similar days were examined. While graphical comparisons were conducted on all seven days for the ships of interest, the three most interesting common-day comparisons are presented for each of the three ship classes.

In the Spruance class comparison analysis (Figures 5 through 7), averaged consumption data for the USS MERRILL, USS CUSHING and USS FLETCHER were used. The corresponding billing periods 5 and 6 were chosen in order to compare the largest available number of ships within a class.[2] The USS MERRILL profiles in this class analysis consisted of combining data from billing periods 5 and 6. The USS CUSHING profiles were taken from billing period 6 (Summer period) while the USS

2 Only three ships were used for each class comparison due to the limited data available. Therefore the reader should note that this does not provide an exhaustive sample of the total number of respective Pacific Fleet ships (20% of Spruance class; 14% of Perry class; 27% of Newport class).

FLETCHER profiles were from billing period 5 (Winter period). Total costs for all three ships were computed using the Summer rate charges in order to make a cost comparison.

As in the case of the USS O'BRIEN (see Figure 4), a weekday spline parameter of P = .8 and an average line for weekend days was selected for the three Spruance class ships. Graphical comparisons conducted on each of the seven days revealed the highest consumption occurring on Wednesday and Thursday for all three ships. As one might expect, the Saturday and Sunday set of profiles contained the lowest and most stable levels of power consumption for all three ships. The total averaged KWHs consumed for Saturday and Sunday differed by only 150 KWHs.

Figure 5, the Monday profile comparison, illustrates the tendency of the profile curves of USS MERRILL and, to a lesser extent, USS FLETCHER to remain generally level throughout the day. The USS MERRILL and USS FLETCHER profiles could be represented by an average line without much loss of consumption pattern details, whereas the USS CUSHING's profile starts at a very low level and then reaches a high plateau as the workday commences and remains at this level until mid-afternoon. The total costs for all three ships on the Monday comparison were very close and resulted in a maximum difference (highest minus lowest ship total cost) of only $30.68 which is less than two percent of the average electric bill.

The spline curves in the Wednesday profile comparison (see Figure 6), show that each ship experiences high peak levels of consumption during the first half (7 a.m.-11 a.m.) of the typical workday. Figure 6 also demonstrates the importance of using graphical analysis rather than relying solely on total cost computations. Notice that the electric bill for the USS MERRILL and USS FLETCHER differ by less than two dollars for Wednesday; the USS FLETCHER's profile remains relatively level throughout the day, while the USS MERRILL's profile is more variable.

The analysis conducted on the weekend usage provided something of a surprise in the sense that one might expect stable KWH usage for each ship to equate to equal overall average KWH values between the three ships. However, the Saturday profile comparisons in Figure 7 show significantly different overall mean KWH levels of consumption for the three ships which resulted in a relative maximum difference of approximately six and one-half percent of the overall average electric bill.

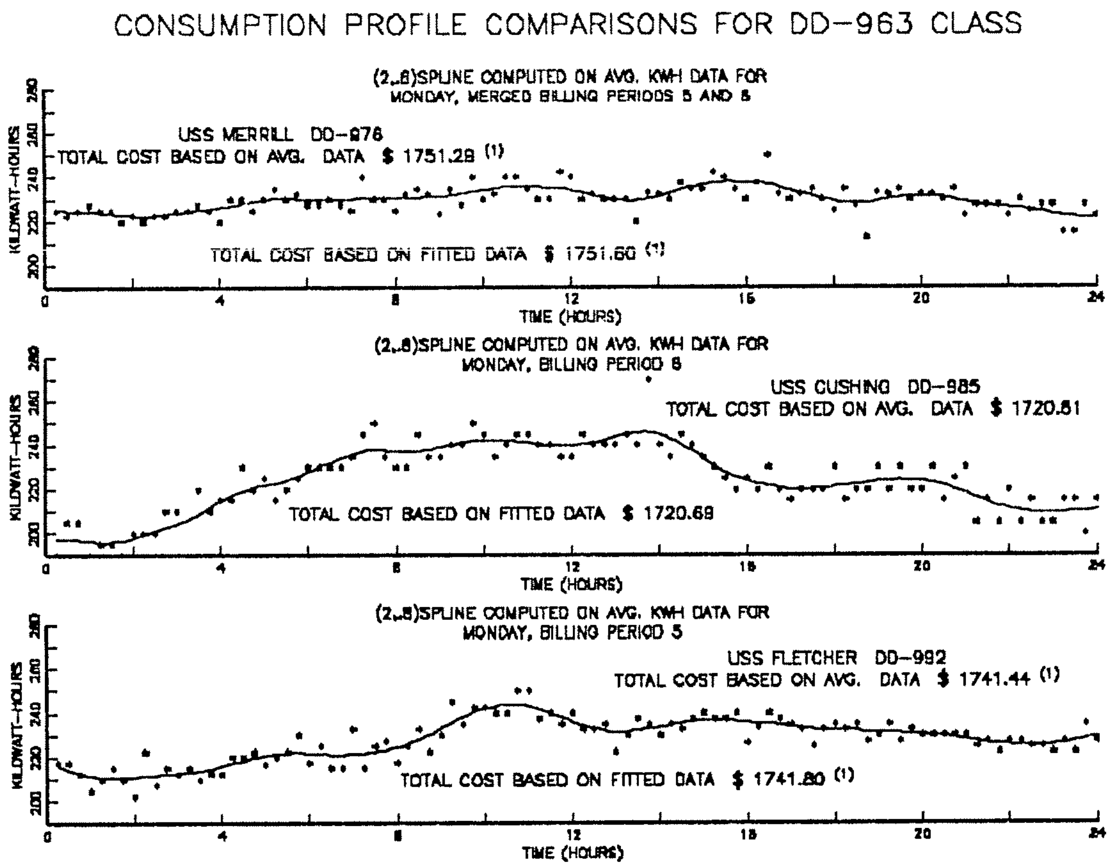

Figure 5. Monday Consumption Profile Comparisons for the Spruance (DD-963) Class: (1) Summer rates were used in billing period 5 in order to compare costs.

CONSUMPTION PROFILE COMPARISONS FOR DD-963 CLASS

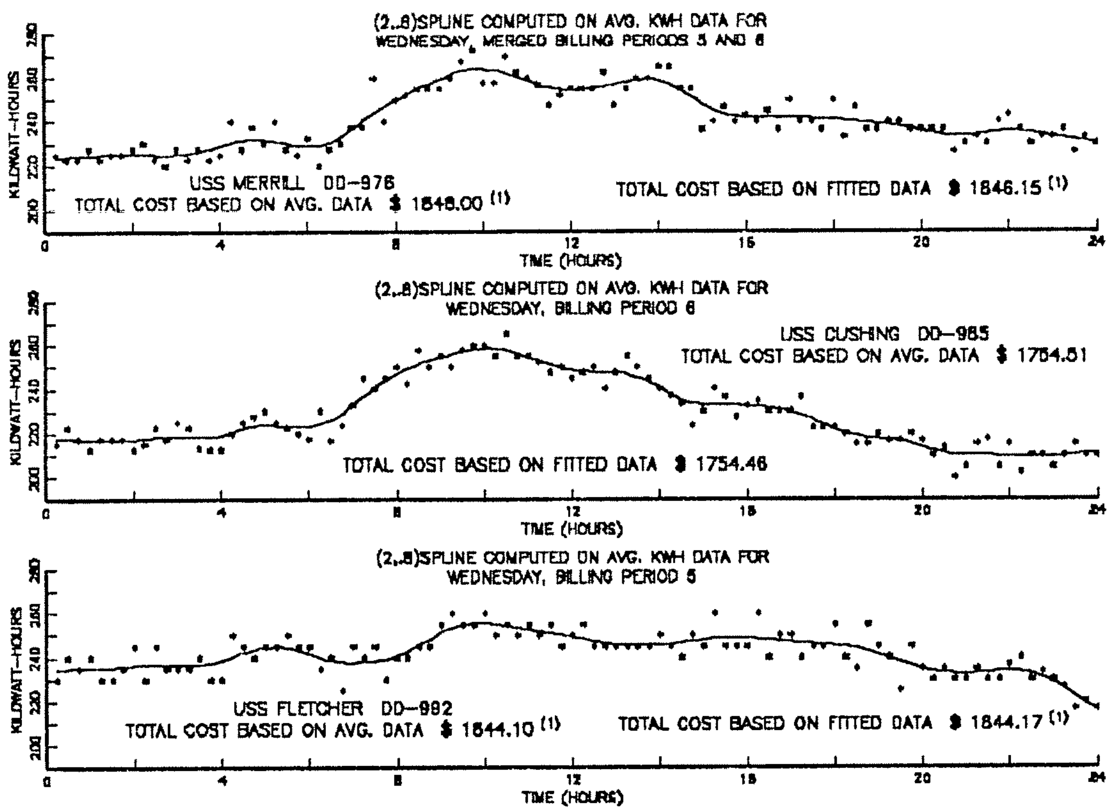

Figure 6. Wednesday Consumption Profile Comparisons for the Spruance (DD-963) Class: (1) Summer rates were used for billing period 5 in order to compare costs.

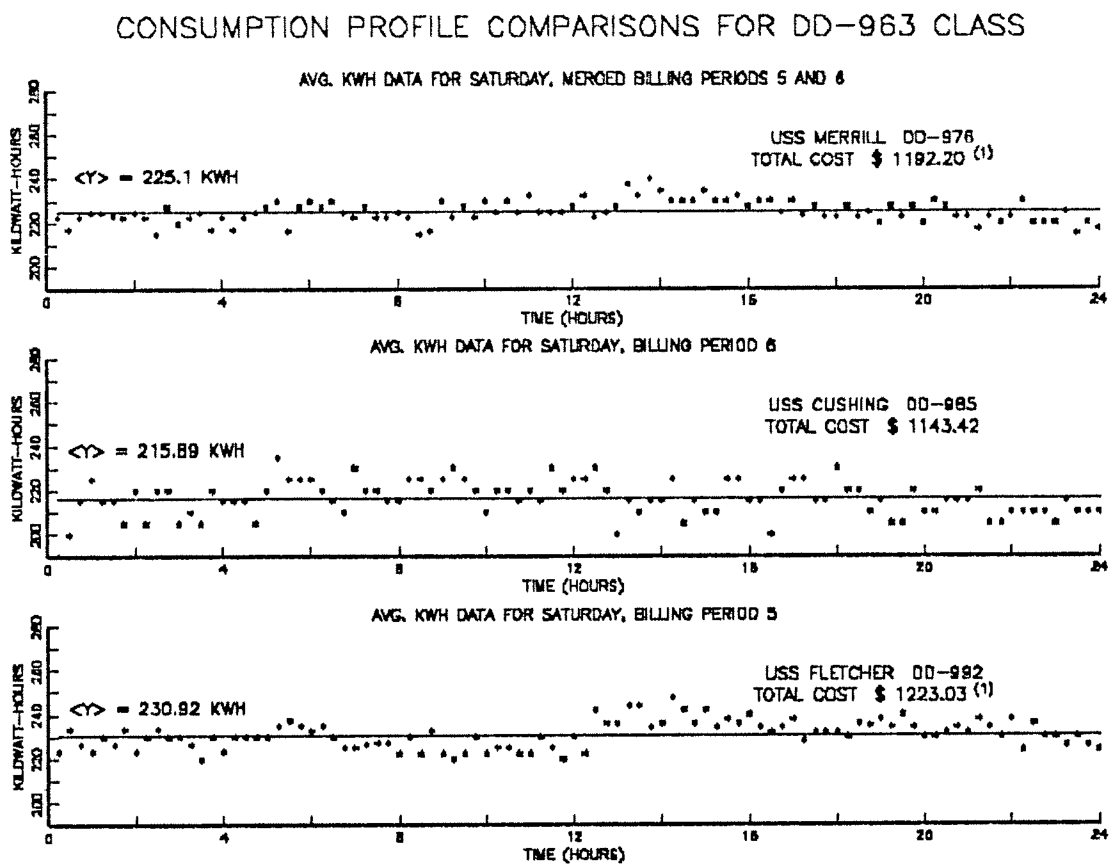

Figure 7. Saturday Consumption Profile Comparisons for the Spruance (DD-963) Class: (1) Summer rates were used in billing period 5 in order to compare costs.

In the Oliver Hazard Perry class comparison analysis (Figures 8 through 11), averaged consumption data for the USS REID, USS LEWIS B. PULLER, USS COPELAND and USS THACH were used. The initial class analysis was conducted on the first three of these ships (Figures 8 through 10) since their common in-port period corresponded to billing periods 3 and 4 (Winter: Feb.17 - Apr.19). This comparison was hindered by the limited amount of data available for each of the three ships. As a result, both the USS REID and USS LEWIS B. PULLER profiles consisted of only two weeks of data and the USS COPELAND profile consisted of three weeks of data, perhaps the cause of the smoother profiles for this last ship.

The Perry class frigates are similar to the larger Spruance class destroyers in that they are modern-era and very electrical dependent. Since these ships also demonstrated a wide range of electrical demand throughout the weekdays, P=.8 was chosen for the spline smoothing curves. The average line was again used for the weekend days. As in the Spruance class analysis, the largest amount of energy was consumed during mid-week (e.g., Thursday) for all three Perry class ships. No comparison was made of Wednesday consumption levels since sufficient data was not available for this day. In contrast to the Spruance class ship analysis, the Perry class profiles for Friday and Saturday exhibited a relatively wider range of power usage during the workday. While shipboard maintenance level information was not available for these three ships, the differing levels of demand on Friday and Saturday may be due to the differences in the ships missions. The USS LEWIS B. PULLER and USS COPELAND are reserve duty units and could have been conducting their heavier workloads and training closer to the weekend while the USS REID, an active duty unit, may have been on a reduced work load.

Figure 8, the Tuesday profile comparison, illustrates the USS REID and USS COPELAND's within day similar patterns of power usage. The USS LEWIS B. PULLER's demand level (middle plot) remains relatively stable throughout the day, however at a consistently higher level than the other two ships. The total costs for all three ships on this Tuesday comparison was close and resulted in a maximum difference of only $54.42 which is less than six percent of the average electric bill. Figures 9 and 10 demonstrate graphical disparity (in average KWH values between the three ships) throughout most of Thursday and Saturday. In contrast to the Tuesday profile cost and consumption comparison, the relative maximum difference on Thursday and Saturday was twenty-five and twenty-nine percent of the respective average electric bill.

One can also observe from Figures 8 through 10 that the USS LEWIS B. PULLER (middle profile) has consistently higher power consumption levels. This was somewhat unexpected when one considers that the USS REID (top profile) is the only active unit of the three ships. This finding of high consumption levels for reserve units tends to refute the notion that there is any significant reduction in electrical usage for a reserve unit versus an active unit of the same class.

Finally, Figure 11 is presented to demonstrate the large increase in electrical consumption for a Perry class ship (USS THACH) during the peak Summer months, relative to the Winter consumption levels shown in Figures 8 through 10. In comparing daily consumption averages with the USS LEWIS B. PULLER (the biggest power consumer of the previous three ships), the USS THACH consumed 14 KWHs (194 KWH vs. 180 KWH) more on Tuesday, 9 KWHs (196 KWH vs. 187 KWH) more on Thursday and 14 KWHs (181 KWH vs. 167 KWH) more on Saturday. The levels of maintenance for these four ships were unavailable; differences in work level may explain the differences in consumption levels. However, other factors such as sea water injection temperature and air temperature for the San Diego Bay area could be explanatory as well. For example, in 1990, the average temperature in the San Diego Bay area for July was 72.3 ° F while for March it was 58.7 ° F [Ref. 4].

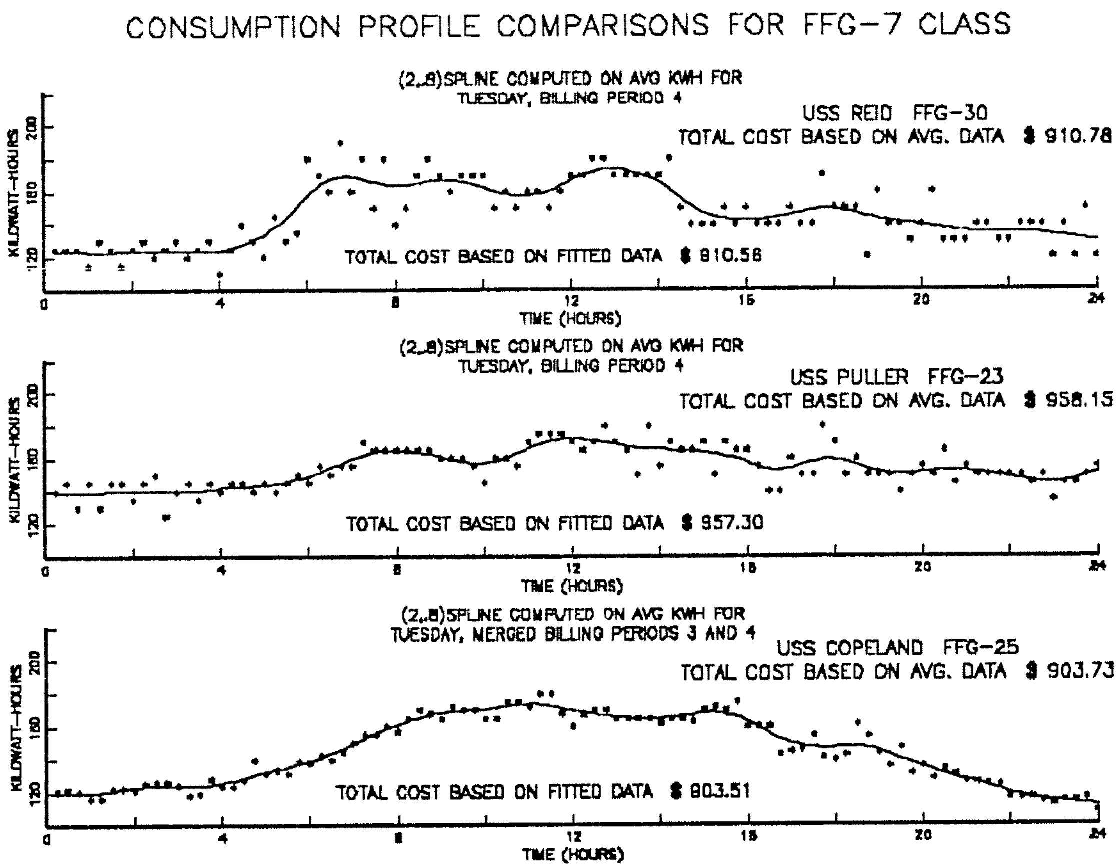

Figure 8. Tuesday Consumption Profile Comparisons for the Perry (FFG-7) Class

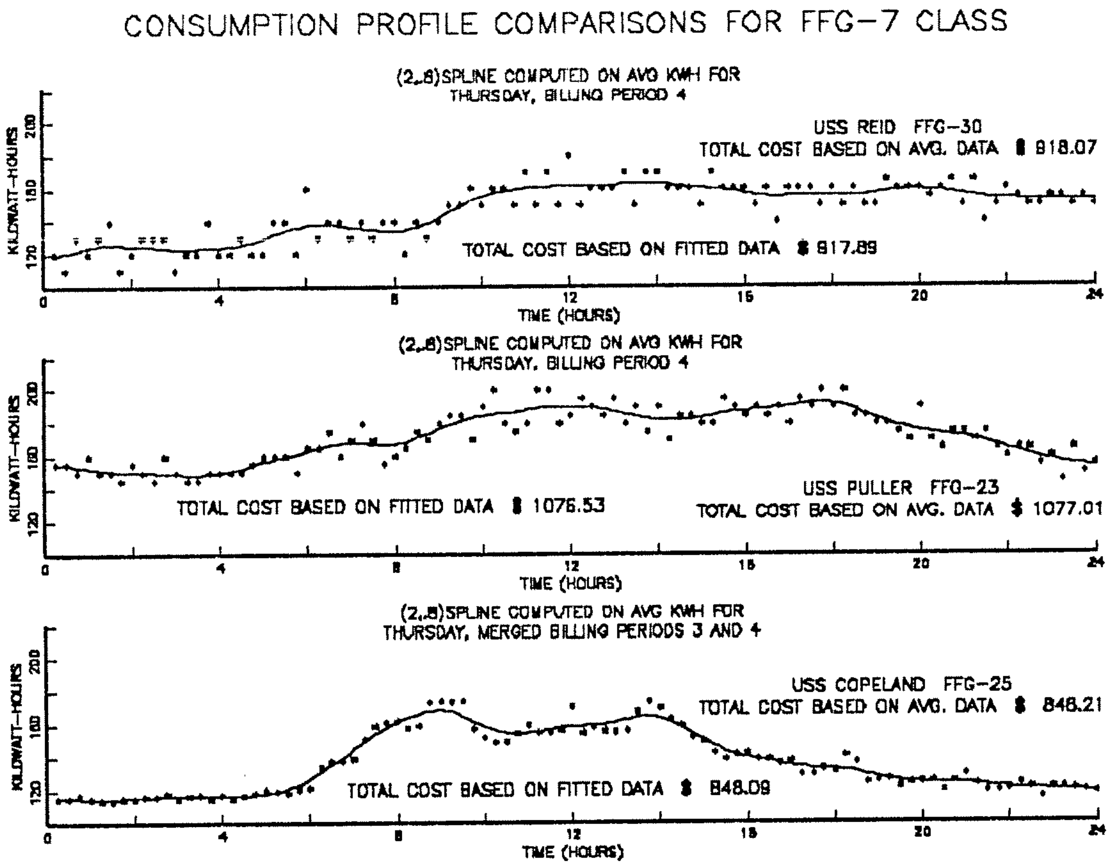

Figure 9. Thursday Consumption Profile Comparisons for the Perry (FFG-7) Class

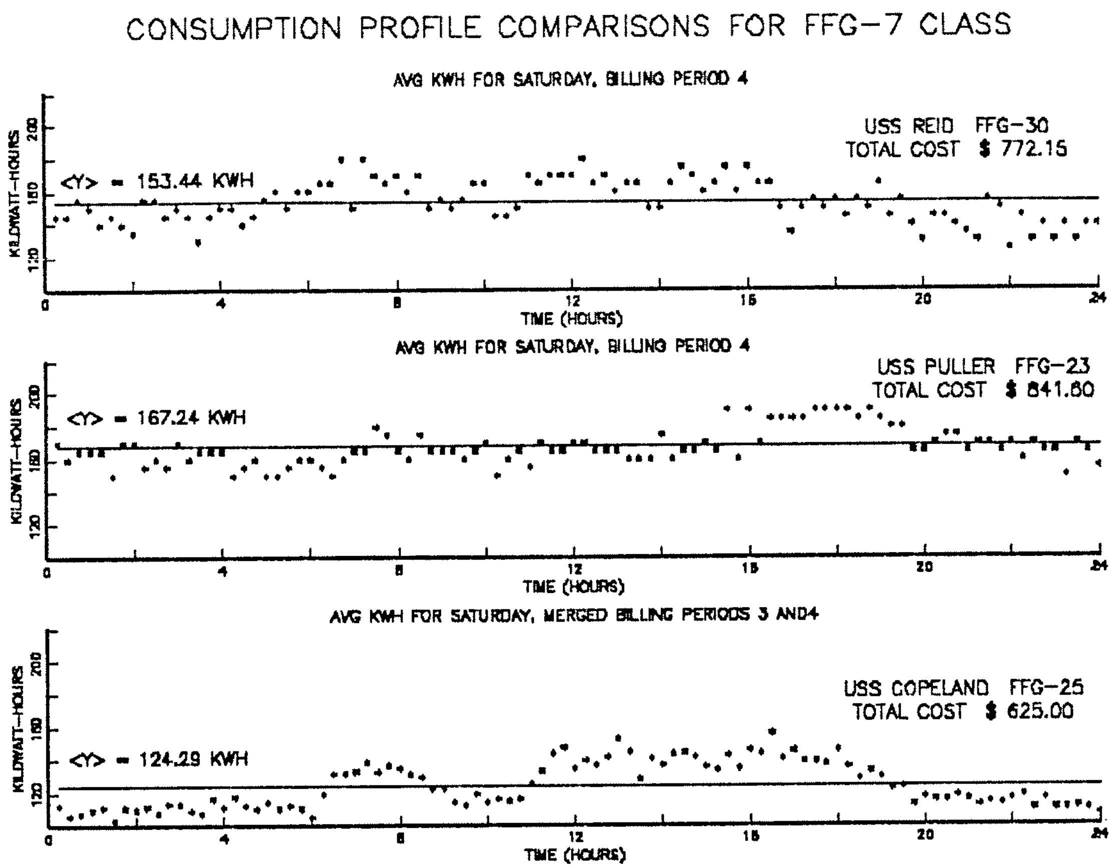

Figure 10. Saturday Consumption Profile Comparisons for the Perry (FFG-7) Class

CONSUMPTION PROFILES FOR USS THACH FFG-43

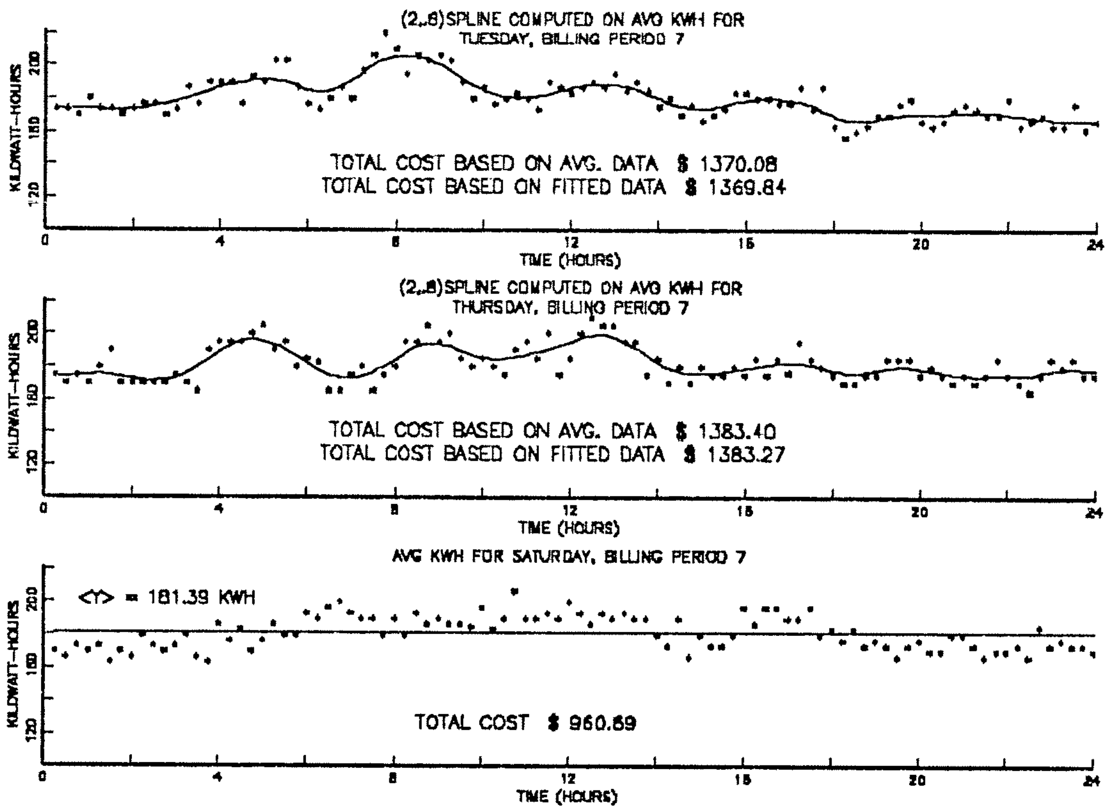

Figure 11. Tuesday/Thursday/Saturday Consumption Profiles for the USS THACH FFG-43

In the amphibious Newport class comparison analysis (Figures 12 through 14), averaged consumption data for the USS PEORIA, USS BRISTOL COUNTY and USS SCHENECTADY were used. Each ship's consumption profiles consisted of at least three weeks of data for the respective billing periods, so the resulting curves were fairly smooth. As in the Perry class comparison, the common in-port period corresponded to

billing periods 3 and 4 (Winter periods). When comparing the USS PEORIA's consumption level during billing period 7 (see Figure 3) with those consumption levels in the following figures, one can observe lower (approximately twenty percent) demand for power during the Winter billing periods.

Of the three class comparisons, the three ships examined in the Newport class had the most consistent profile comparisons, for each of the seven days. Total daily consumption was about the same Monday through Friday for the USS BRISTOL COUNTY and USS SCHENECTADY. The USS PEORIA did consume slightly more power during mid-week (e.g., Wednesday and Thursday). As in the previous two class analyses, the weekend profiles for the Newport class remained relatively stable throughout the day.

Figure 12, the Monday profile comparison, demonstrates the closeness among all three ship's consumption levels as well as total costs. In contrast, the USS PEORIA's Wednesday profile (see Figure 13, top plot) illustrates three distinctive areas of high consumption (6 a.m., 9 a.m., 2 p.m.).

Total cost comparisons revealed that the Wednesday electrical bills generated the largest maximum difference of all seven days, yet was only $58.10. This was equivalent to only ten percent of the overall mean cost of the three ships for a typical Wednesday. Utilizing total costs based on averaged data shown in Figures 12 and 14, the maximum differences were $4.44 and $23.29 which corresponded to less than one percent and five-and-one quarter percent of the respective daily averages.

This particular class analysis seemed to indicate that a set of class profiles (one for each day of the week) for the combined billing periods 3 and 4 may be very accurate for predicting costs. The reader is once again cautioned that these three ships only represent 27% of the total class number in the Pacific Fleet that might berth at NAVSTA, San Diego; the activities performed by the ships in port are not known and may or may not represent a wide range of possible activities, along with their required power consumptions.

In summary, the three graphical class comparisons discussed above, seem to indicate that different ships from the same class may contribute some degree of variability on daily overall usage for the class. Additionally, power demand seems to vary throughout the day.

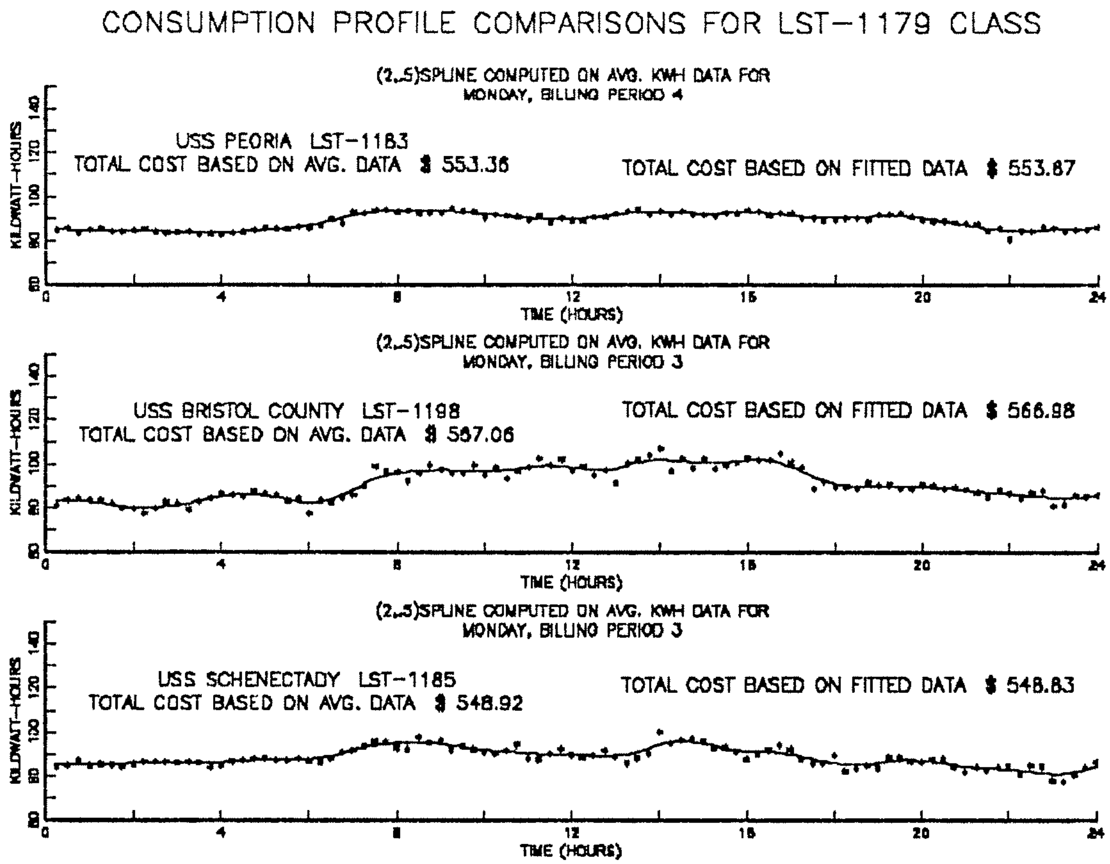

Figure 12. Monday Consumption Profile Comparisons for the Newport (LST-1179) Class

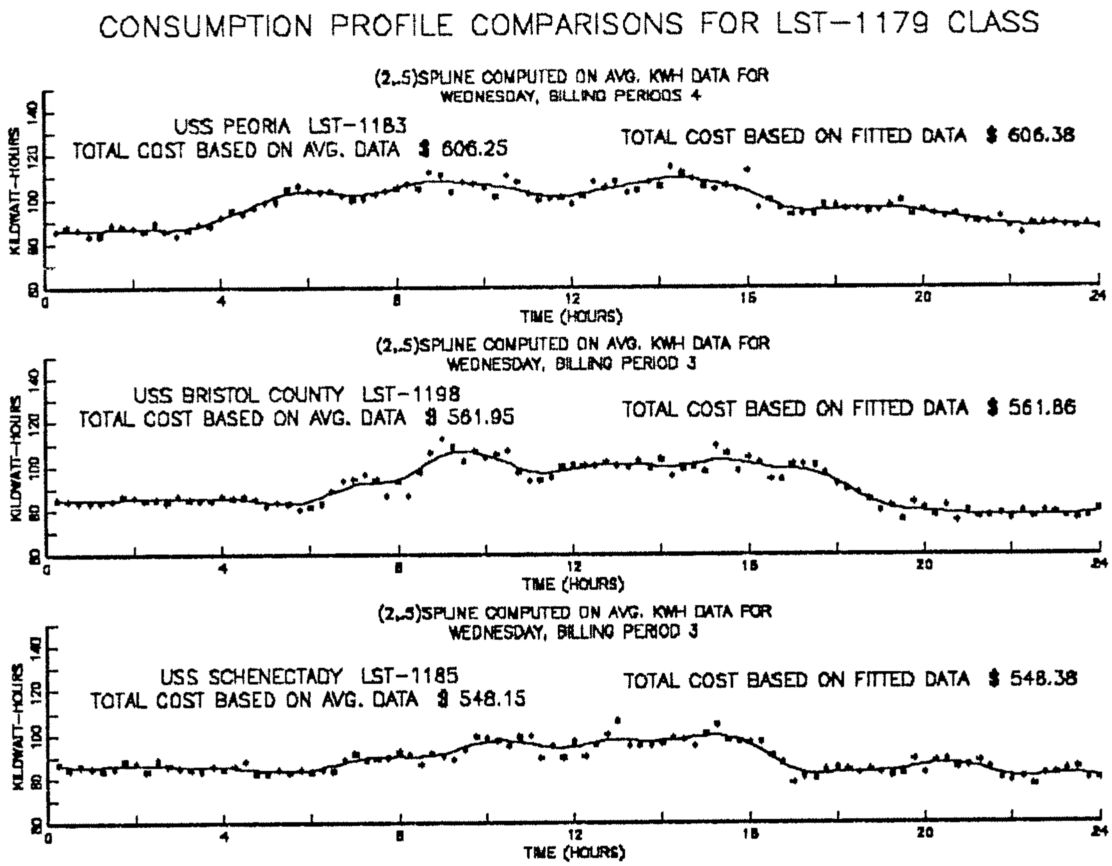

Figure 13. **Wednesday Consumption Profile Comparisons for the Newport (LST-1179) Class**

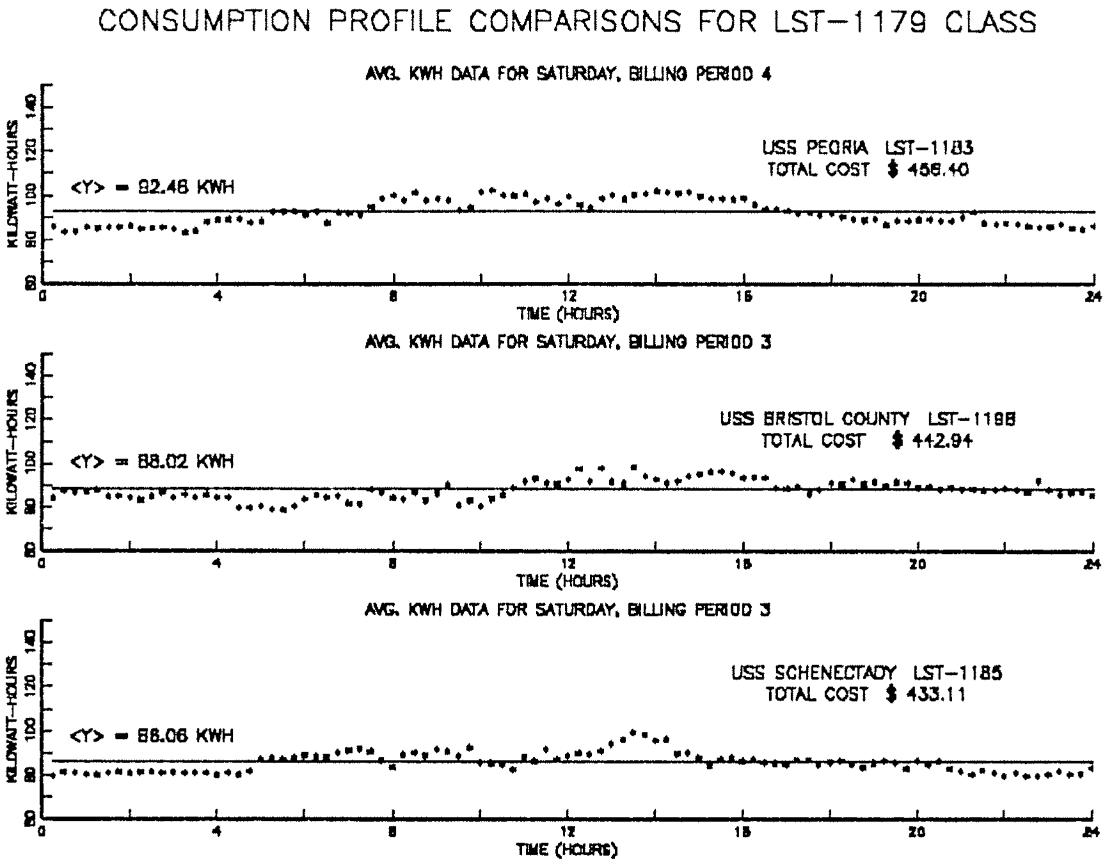

Figure 14. Saturday Consumption Profile Comparisons for the Newport (LST-1179) Class

B. STATISTICAL COMPARISONS

A two-way analysis of variance (ANOVA) test was applied to the averaged data in each of the three aforementioned ship classes to aid in measuring the effects (in terms of variability) of ships and time periods on daily class profiles.[3] For each of the following class analyses, the two-way ANOVA test used the three ships from the respective class and specific segments (periods) of time. These two inputs are also referred to as treatment and block sources of variation respectively [Ref. 5: p. 10]. The two-way ANOVA results included an F-statistic for ships (treatment) and one for time (block). These statistics provide measures of the effect these two sources have on the overall daily power usage.

The F-statistic for ships was used to determine how close (indicated by a small F-statistic) or diverse (indicated by a large F-statistic) the total consumptions are, between the ships evaluated. Thus, if small F-statistics for ships were found for each of the seven days of a particular class analysis, then this would tend to indicate that daily consumption levels for these ships should be fairly consistent for each of the days. The time periods chosen for the class analyses were 1 hour blocks (i.e., each 1 hour block consisted of four data points: 00:15 a.m.-1 a.m., 1:15 a.m.-2 a.m., etc.). The F-statistic for time was used to identify how level (indicated by a small F-statistic) or erratic (indicated by a large F-statistic) the daily consumptions are throughout the given day.

1. Class Analyses

The two-way ANOVA results for these Spruance class ships resulted in a large ship F-statistic for four of the seven days. This indicated that there were diverse usage levels between the three ships for Wednesday, Thursday, Saturday and Sunday. The Wednesday and Thursday profiles were described in the Graphical Comparisons section as having the highest levels of power usage. Thus, these two days being the busiest days of the week make it somewhat unlikely for power usage levels to be consistent among the three ships from hour to hour. For example, a ship conducting major weapon systems tests throughout the in-port period will have higher operating levels than another ship that is only conducting routine maintenance. The weekend usage was described previously as being relatively stable. However, the differences in the average KWH usage among the three ships shown in Figure 7 (225.1 KWH, 215.89 KWH, 230.92 KWH) is enough to cause this source of variation to be quite large.

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3 The two-way ANOVA can also easily be applied to consumption costs by multiplying the averaged KWH data by the appropriate charge rates.

The F-statistic for time was largest for Wednesday which indicated that this day has the biggest hour-to-hour variation. Additionally, since Wednesday contained both a large ship F-statistic and F-statistic for time, then the resulting class profile for this day would be accompanied by a relatively large (with respect to remaining days of the week) standard deviation. The F-statistic for time was smallest for Saturday which indicated a relatively flat level of usage throughout the day for each ship.

Additionally, the two-way ANOVA was conducted to statistically support the notion that consumption levels differ significantly in the cases of: (1) far-ranging billing periods (e.g., billing pd. 2 vs. billing pd. 7) and (2) unequal mean KWH values between days for a particular ship (e.g., Monday vs. Wednesday). For example, comparisons of data from USS O'BRIEN (billing pd. 7), USS HILL (billing pd. 9) and USS CUSHING (billing pd. 3) resulted in large ship F-statistics for all seven days; perhaps indicating that comparisons between ships from different seasons may produce more diverse usage patterns than if the same ships were from the same season or closer billing periods. A Monday versus Wednesday comparison of data from USS MERRILL (billing pds. 5 and 6) also resulted in a large difference between days. The statistical results of this latter case can easily be seen in graphical form by comparing Figures 5 and 6. However, the two-way ANOVA and graphical analyses did consistently show equal mean KWH values for Saturday and Sunday profiles for a particular ship. This was to be expected since the work level on both of these days is relatively stable.

The two-way ANOVA results for these three Perry class ships resulted in a large ship F-statistic for all six days examined (no data for Wednesday). The consumption levels of the three ships differed for each of the six days. The F-statistic for time was small (insignificant time differences) for Monday and Friday, which indicated a relatively flat level of usage throughout the day for each of the three ships. Since the remaining four days had large F-statistics for time and large ship F-statistics, the profile standard deviation is large for these four days. The large standard deviation indicates that the resulting daily class profile would not be a very precise estimate of expected power consumption for any given ship.

The two-way ANOVA tests for the Newport class analysis resulted in large ship F-statistics for six of the seven days examined. The ship F-statistic for Monday was moderately small, which indicated that there was a slight degree of diversity in the usage levels among the three ships. One can observe from Figure 12, the Monday profile comparison, that the USS BRISTOL COUNTY (middle plot) did indeed consume slightly more power than either of the other two ships from 8 a.m. to 3 p.m. The F-

statistic for time was small for Saturday and Sunday; indicating that the demand for power during the weekend (for these three ships) is about the same. Similar to the Spruance class results, the largest F-statistics for time occurred on Wednesday and Thursday, signifying that these two days were the most variable across the day.

It is of interest to note that while large F-statistics did result for most of the days in the Newport class analysis, the magnitude of these statistics were not as large as those of the previous two classes. Thus, the daily Newport class profiles (based on these three ships) will have smaller standard deviations about the mean daily levels of usage.

IV. APPLICATIONS

A. BUDGET PLANNING

Perhaps the most immediate application for these profile curves and associated cost computations is in the area of billing validation and budget forecasting. Since the CINCPACFLT Comptroller's office receives electric bills for its ship's shorepower usage each billing period at NAVSTA, San Diego, then the applicable ship's profile costs for that billing period could be totaled and compared against the billing statement issued by PWC Utilities, San Diego, Ca.. The purpose for the comparison would be to determine how close averaged consumption profiles and their associated total costs are to PWC's empirical means of billing.

In the event Third Fleet accountants support the idea that these profile curves do indeed tend to resemble actual power demands, then fleet forecasters can estimate utility costs for future billing periods based on advanced knowledge of future ship in-port schedules. The ability to estimate future utility costs should prove to be a helpful tool in such important instances as the end of the fiscal year, which lies within the expensive Summer time-of-use period.

As an illustration of how utility billing validation might work, consider the following in-port ship activity which actually occurred at piers 2 and 13 during billing period 9 (Aug. 18 - Sep. 19) in 1990:

ship & hull no.	connect date/ time	disconnect date/ time
USS CORONADO AGF-11	8-18 / 00:15 a.m.	8-21 / 8:15 a.m.
USS LEAHY CG-16	8-18 / 00:15 a.m.	8-21 / 9:00 a.m.
	8-23 / 3:45 p.m.	9-15 / 11:45 p.m.
USS DULUTH LPD-6	8-18 / 00:15 a.m.	8-27 / 5:30 a.m.
	8-30 / 12:15 p.m.	9-13 / 4:45 p.m.
	9-14 / 12:45 p.m.	9-19 / midnight
USS KINKAID DD-965	8-24 / 2:00 p.m.	8-27 / 3:15 a.m.
USS HILL DD-986	8-28 / 8:00 a.m.	9-19 / 8:30 p.m.
USS MERRILL DD-976	8-31 / 12:30 p.m.	9-19 / midnight

The PWC Utilities Duty Desk office maintains this shorepower connection information for every pier. The Comptroller's office would need this information in order to compute the estimated electric bill for a particular billing period.

Since the length of the study period, lack of instrumentation on the remaining piers and unforeseen events (e.g., Persian Gulf War deployments) prevented the construction of consumption profiles for every Third Fleet ship that berthed at NAVSTA, San Diego, some generalizing prediction methods are unavoidable when considering situations like the above schedule. First of all, since the USS CORONADO was the only AGF to berth at pier 13 throughout the research period, its actual consumption data was used to compute the total cost during the short pierside usage. Normally, using a ship's actual consumption data would not be an option for the forecaster since such data would be hard to obtain in a timely manner; or in the case of projecting costs in advance (e.g., the forecaster has advanced knowledge of Pacific Fleet ship's port schedules for the next billing period), those ships which have no profiles (nor class profiles) would make it difficult to accurately estimate its electric bill. In the case of the short port visit by the USS KINKAID, the option exists to allow for the profiles of the USS HILL or USS MERRILL to represent a fair, at best, approximation of the USS KINKAID's actual utility bill (due to system errors, KWH data was not available for the USS MERRILL during this billing period). The other option would have been to use daily class profiles, if they were available for this period, to estimate the daily costs. Since daily class profiles were not available for this period, the convention chosen for this illustration was to use the highest profile curve among the similar ships in the billing period so as to purposely over estimate costs rather than under estimate. Thus, the pertinent day profiles from the USS HILL were used to represent the estimated power demand of the USS KINKAID. As for the remaining ships, adequate weeks of data existed to construct profile curves for this billing period. These consumption profiles and associated KWH time-of-use totals are contained in Appendix C for inspection.

Matching each ship's day of the week in port (USS CORONADO excepted) with the appropriate day's usage profile from Appendix C, a total bill of \$ 149,887.56 for power consumed at piers 2 and 13 during billing period 9 is achieved. The following is a breakdown of individual ship costs and total days in-port receiving shore power:

USS CORONADO.......\$ 5,053.64...........3.3 days

USS LEAHY................\$ 44,699.12..........27.0 days

USS DULUTH.............\$ 26,623.84..........28.8 days

USS KINKAID............\$ 3,565.27............2.5 days

USS HILL....................\$ 36,950.79..........22.0 days

USS MERRILL............\$ 32,994.90..........19.5 days

Similar calculations for the 11 remaining piers would produce an estimated overall ship utility bill for billing period 9. This total cost took into account partial days of shorepower connection for a particular ship. This total cost figure above *does not take into account* so called coincidental and non-coincidental demand surcharges which are also applied to the billing statement. These two charges are end of month surcharges that are based on the highest demand periods experienced by the city as well as the Naval Base respectively. The occurrence of these two peak demand periods are unknown until an end-of-billing-period assessment is conducted and therefore are beyond the scope of this study.

B. CONSERVATION EFFORTS

In early 1988, an energy study was conducted by staff members of Cruiser-Destroyer Group One, San Diego which explored alternative means of reducing and conserving in-port energy usage. The study was primarily concerned with illustrating cost savings that could be incurred from: (1) installation of the electrical metering system, which at the time was still in the development phase; (2) incentive and penalty-based rate structure, which is the current PWC utility rate structure in use, and; (3) shifting to other energy sources (e.g., shipboard produced energy generated by the engineering plant). Two energy conservation measures of particular interest that were proposed but to date have not been implemented include:

- establish the policy of using gas turbine and diesel generators on selected classes of ships during peak demand periods in the Summer months.
- utilize the Command Early Warning Net (a local based broadcast frequency) to initiate energy reduction measures such as electrical load shedding (explained below). [Ref. 2: p. 3]

The first proposed measure seems to be highly unlikely to be placed in effect due to the various obstacles to such. Some immediate concerns include pre-planned in-port maintenance schedules of most ships that include shutting down the engineering plant; the manpower required for large ships to start-up their plant may not be cost effective even if fuel prices were low, due to the aforementioned "peak demand periods" being only a 2 to 4 hour time frame; under current budget procedures, ships are allotted a certain amount of fuel for the fiscal year and running the engineering plant in port would deplete fuel allocations available for underway operations.

The second proposal, however, has more cost savings potential without implications of jeopardizing fuel allocations or necessary maintenance plans. Electrical load shedding is a means for a "customer" to avoid the high cost effects of demand surcharges such as

the coincidental and non-coincidental rates by shutting off or reducing power to non-essential equipment. PWC Utilities, San Diego, has contracted for a firm to predict (by means of a regression model) when SDG&E power demand will peak during the billing period. The firm gives three predictions for each billing period; normally this warning is telephoned in to the PWC Utilities office within about 5 hours in advance of the 4-hour peak demand prediction period. As stated earlier, the actual occurrence, which will be a 15-minute interval, of the SDG&E peak is unknown until the end of the billing period. However, given that these predictions have a historical record of accuracy, it becomes prudent for the "customer" to reduce his power demand within the predicted 4-hour time frame. Currently, PWC relays the received prediction warnings to their "customers" (ships excepted) so that voluntary load shedding plans can be put into effect and subsequently result in reduced electric bills.

If a similar relay procedure was initiated to inform ships of peak load predictions, large savings could be realized when one takes into account the number of ships in port at any given time. As part of this research, a pilot study was conducted in November and December of 1990 which involved five ships berthed at piers 2 and 13. These ships were given same-day advance notice of peak power predictions and were asked to conduct load shedding on these particular days. The responses varied, with most ships not recording any significant efforts to reduce demand. In hindsight, this was to be expected when considering that it was during the holiday season and most of the ships chosen had just arrived back from extended deployments (minimum manning levels). Additionally, there was no incentive available to offer the ships in exchange for their efforts to conserve or reduce.

However, despite these obstacles, the crew of the USS LEAHY CG-16 was quick to implement an effective load shedding plan which produced a rather large list of equipment items either secured or placed in standby upon being informed of peak load predictions. A measure of how much savings resulted was not computed, however the power ratings of those pieces of secured equipment could be used by shipboard personnel to obtain an estimate of the savings generated (e.g., equipment rating (KWH) x applicable charge rate ($/KWH) x no. of 15-minute time intervals that equip. was secured).

Currently, the PWC Utilities Engineering building contains equipment that can measure the instantaneous drop (rise) in power demand for each berth location at piers 2 and 13. This system has the capability of identifying which pieces of shipboard equipment contribute most to power usage. If such equipment items were identified, efforts could then be made to perhaps schedule the use of these pieces of equipment

during a less expensive time-of-use period (e.g., shift energy usage to the semi-peak or off-peak period from the on-peak period). The following example demonstrates how efficient use of energy could help in reducing budget expenditures for electricity.

The USS BARBEY, a Knox class frigate, was in port at pier 2 from May 24 until June 13, 1990 (billing period 6). The following is a breakdown of the total Wednesday average KWH usage and associated cost (using Summer charge rates):

total off-peak usage	total semi-peak usage	total on-peak usage	total cost
3271.67 KWH	4005.00 KWH	3213.33 KWH	$ 840.13

If ten percent of the total on-peak KWH usage (321.33 KWH) were shifted to either one, or combination of both, semi-peak periods (6 a.m.-11a.m., 6 p.m.-10 p.m.), then the new total cost for that day would be $827.76. This savings amount is small but would add up to a significant total savings if efficient measures such as this example were used for the remaining 14 weekdays that the USS BARBEY was in port.

A Knox class ship was purposely chosen to illustrate the conservation measures since the in-port time at pier 2 for ships of this class was significant (e.g., three Knox class ships in-port time combined for a total of 38 days during May - Aug. 1990) and the ship's consumption levels were relatively low, compared to the Perry class frigates; this seems to indicate that larger utility savings may be possible for those ships which operate at higher levels of power, such as the Spruance and Perry classes.

V. CONCLUSIONS

The decision to use data from similar ships to form a class profile becomes a judgment call for the budget forecaster which will be heavily weighted by his or her need for accuracy in prediction of the utilities costs. The three class analyses presented in this study demonstrated the use of two criteria (graphical comparisons and numerical analysis of average KWH data) as decision aids for the forecaster. Application of these tools to the three classes resulted in large variability in power usage patterns, among ships in the same class, for a majority of the days. This seems to indicate that despite design and equipment similarities of ships within the same class, other factors such as work schedules may be contributing to the different levels of usage.

The Spruance and Perry class analyses both resulted in higher and more variable usage patterns than was found for the Newport class ships. Since the Perry class ships are smaller and lighter than the Newport class ships, this seems to indicate that there is no positive correlation between ship size and level of power usage.

Since the Spruance and Perry class analyses did identify large ship differences, this seems to indicate that those ships which were operating at the highest power levels might be able to reduce power consumption and subsequently lower the ship consumption to that of the most efficient ship.

For all three class analyses, the mid-week period (e.g., Wednesday and Thursday) was primarily observed to use the most energy. In most cases, Wednesday was found to be the most active (high peak levels) day. This seems to suggest that there are significant differences in KWH levels throughout certain days of the week. Thus, good profiles of these "active" days should provide better total cost estimates rather than relying one single average KWH value for each ship class.

For all the ships tested, the KWH values for the weekend days were similar enough to conclude that Saturday and Sunday consumption could be combined into one weekend profile for each ship. The Perry class analysis of the weekend days did show high maximum differences in mean levels; this could be linked to the fact that some ships were Naval Reserve units and may have been operating at higher levels during the weekend.

The profiles contained in Appendix C are intended for use as forecasting aids as well as for ship commanders to gauge their own demand levels against a similar profile contained in the appendix. The possible shortfalls of these profiles are:

- The specific onboard maintenance activities were unknown and probably varied from ship to ship in levels of intensity.
- In the case of the class profiles, the number of ships available is not large; the estimated ship-to-ship variability may not be accurate.

Finally, a word on the limitations of the study with regard to the environment is warranted since the type of ships studied in this thesis are also homeported in various locations throughout the world. Since the shipboard electrical consumption data was taken solely from NAVSTA, San Diego, the reader is cautioned that power consumption levels may differ for similar ships located in different ports (environments) due to comparative differences in seawater temperatures and air temperatures throughout the year. These factors would definitely have an effect on the amount of power demanded by large machinery such as A/C units. These two factors along with identifying which electric driven pieces of equipment have significant effects on power demand were not explored in detail. Factors such as these do seem to be candidates as significant explanatory variables and should be considered in future shipboard energy consumption studies.

APPENDIX A. TABLES

The following tables contain information on:

1. List of ships participating in the study, arranged by pier berth location.
2. List of billing periods used to compute electrical consumption costs.

Table 1. LIST OF SHIPS FROM WHICH DATA WAS COLLECTED DURING 01 JAN. 1990 - 19 JUN. 1991 PERIOD

Pier 2: ship & hull no.	days in-port	% of days by season	class
USS CUSHING DD-985 *	104 days	91% Winter	↑
USS ELLIOTT DD-967	3 days	100% Winter	:
USS FLETCHER DD-992 *	85 days	83% Winter	:
USS HILL DD-986	95 days	60% Winter	Spruance
USS KINKAID DD-965	46 days	80% Winter	destroyers
USS MERRILL DD-976 *	74 days	95% Summer	:
USS O'BRIEN DD-975	42 days	81% Summer	↓
USS BAGLEY FF-1069	5 days	100% Summer	↑
USS BARBEY FF-1088	27 days	100% Summer	Knox
USS COOK FF-1083	13 days	100% Winter	frigates
USS DOWNES FF-1070	3 days	100% Summer	↓
USS COPELAND FFG-25 *	35 days	71% Winter	↑
USS PULLER FFG-23 *	13 days	100% Winter	:
USS JARRETT FFG-33	10 days	100% Summer	Perry
USS TISDALE FFG-27	16 days	100% Winter	frigates
USS REID FFG-30 *	12 days	100% Winter	:
USS THACH FFG-43	21 days	100% Summer	↓
Pier 13: ship & hull no.	**days in-port**	**% of days by season**	**class**
USS PEORIA LST-1183 *	45 days	58% Winter	↑
USS BRISTOL COUNTY LST-1198 *	44 days	89% Winter	: Newport
USS BARBOUR COUNTY LST-1195	11 days	100% Summer	amphibious tank
USS TUSCALOOSA LST-1187	37 days	89% Summer	&transports
USS SCHENECTADY LST-1185 *	17 days	89% Winter	: ↓
USS DULUTH LPD-6	84 days	50% Winter	Austin
USS DENVER LPD-9	45 days	100% Winter	dock ships
USS LEAHY CG-16	194 days	54% Winter	Leahy
USS GRIDLEY CG-21	33 days	100% Winter	cruisers

'*' indicates ship was used in class profile analysis

Table 2. BILLING PERIODS COVERING THE CALENDER YEARS 1990-1

billing period	1990 - 1991 coverage	seasonal rate charge
1	12/18 - 1/18	WINTER
2	1/19 - 2/16	WINTER
3	2/17 - 3/20	WINTER
4	3/21 - 4/19	WINTER
5	4/20 - 5/18	WINTER
6	5/19 - 6/19	SUMMER
7	6/20 - 7/19	SUMMER
8	7/20 - 8/17	SUMMER
9	8/18 - 9/19	SUMMER
10	9/20 - 10/18	SUMMER
11	10/19 - 11/16	WINTER
12	11/17 - 12/17	WINTER

Source: Thomas, J.W.
PWC Utilities Department, San Diego, CA.

APPENDIX B. PROBLEMS ENCOUNTERED

Kilowatt-hour data for ships berthed at pier 13 required a conversion adjustment for the period March 1-September 28, 1990 due to incorrect power factor calculations. During the above period, presumed power factor calculations used for each associated kilowatt-hour reading were actually only *phase angle* calculations and subsequently caused the resultant kilowatt and kilowatt-hour readings to be lower than actual. According to Honeywell system operators, readings were approximately twenty-four to twenty-five percent lower than actual consumption. Equation (1) demonstrates the relationship between the phase angle and power factor:

$$PowerFactor\ (pf) = \cos\left(\left(\frac{100 - PA}{100\,x\,90} \right) \frac{\pi}{180} \right) \qquad (1)$$

where:

phase angle (PA) $\equiv$ the phase relationship between current(I) and voltage(V).

power factor (p.f.) $\equiv$ the measure of ship's overall capacity to convert electrical energy into work.

Thus, an APL2 function was used to convert the daily phase angle calculations into correct power factors. The correct power factors were then divided by the original phase angles to yield the percentage adjustment required at each fifteen minute time interval for each day. This adjustment was then applied to the averaged KWH data. Equations (2) and (3) demonstrate the interrelationships:

$$power(watt - hours) = \frac{(\sqrt{3}\ V_m\ I_m\ pf_m)}{4} \qquad for \quad m = 1,2,3,...,96. \qquad (2)$$

$$adjustment(\nearrow)required = \left(\frac{pf}{PA}\ x\ 100 \right) \approx 0.245 \qquad (3)$$

The percentage adjustment found during this study ranged from twenty-five to thirty-seven percent due to most ships possessing a fluctuating power factor of 0.77 $\pm$ 0.025. The discovery of this power factor miscalculation stressed the importance of data verification as an initial step prior to formal analysis. One's assumption of what range

the output data should fall within based on previous related experiences tends to alleviate unexplainable deviations from otherwise pattern-like ship consumption profiles.

Due to metering system malfunctions on both piers, sporadic null watt-hour data readings (e.g., 0.00) were recorded despite associated normal current readings. In most cases the actual watt-hour data could not be reconstructed which would subsequently produce gaps within the graphical profiles unless averaging of data points were implemented. Table 3 shows an edited portion of a typical set of megawatt-hour data (pier 2).

Table 3. WEDNESDAY (BILLING PERIOD 7) MEGAWATT-HOUR DATA FOR USS OBRIEN DD-975

data pt.	27 Jun '90	04 Jul '90	11 Jul '90	18 Jul '90
1	0.23	0.22	0.24	0.25
2	0.01	0.23	0.25	0.25
3	0.24	0.21	0.24	0.26
.	.	.	.	.
.	.	.	.	.
.	.	.	.	.
45	0.27	0.26	0.28	0.29
46	0.27	0.27	0.28	0.30
47	0.00	0.28	0.29	0.31
48	0.00	0.27	0.29	0.30
49	0.81	0.27	0.29	0.31
.	.	.	.	.
.	.	.	.	.
.	.	.	.	.
94	0.23	0.21	0.24	0.25
95	0.22	0.23	0.25	0.25
96	0.24	0.21	0.24	0.26

Table 3 displays data which had not yet been corrected for random noise level readings (see data pt. 2, June 27) and high aggregate meter readings (see data pt. 49, June 27). The latter case is mostly caused by brief interrupted communications between the Honeywell host computer and the data gathering panels. When communications were restored, the host computer received an aggregate amount of energy used by the ship during the interrupted time period. This type of problem continued to prevail, even as recently as June 10, 1991 at pier 2, designated berth locations 2S and SLOV. This particular problem prevented the use of a fourth Spruance class destroyer in the class comparison analysis.

When electrical consumption data was initially plotted at PWC with no regard for corrective action to null and error data points, the energy profiles were broadly deviant. Any indications of pattern-like behavior in the profiles were masked by such a large y-axis scale. This large scale was required due to the inclusion of extreme error points mentioned above. Even when the monitoring system is complete and ship-by-ship billing becomes possible, these extreme error points will cause billing errors unless a system operator or program is created to exclude/correct these points.

APPENDIX C. POWER CONSUMPTION PROFILES

The following graphs are power consumption profiles for various ships and ship classes which had adequate data collected during the study. These graphs differ only in appearance from the profiles presented in the study. The same procedure of using averaged KWH data was applied with an average line indicating the mean KWH level for the respective time-of-use period(s) that occurred during that particular day.

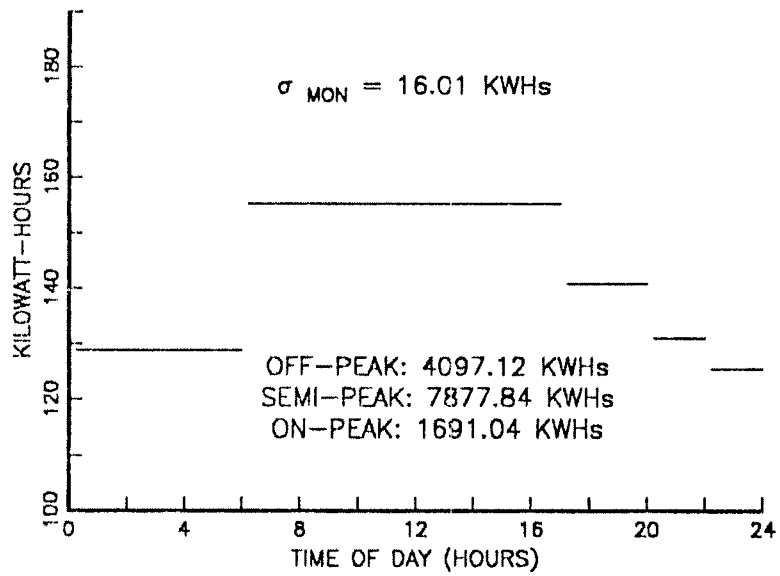
These graphs provide the budget forecaster with means to compute day-to-day estimated electric costs for ships berthed at NAVSTA, San Diego during the applicable billing period. Instead of listing associated costs with the graphs, total KWH usage for off-peak, semi-peak and on-peak time-of-use periods for each graph is annotated. These KWH totaled values can then be multiplied by the respective charge rates to obtain a total cost.

Class profiles are included based on the statistical results discussed earlier. As an indication of how imprecise these class estimates can be, the standard deviation (± 1) for each day (denoted by "σ") is included. It is suggested that the forecaster use these standard deviation values as an adjustment factor applied in such cases as when it is known that a particular ship is conducting in-port maintenance at an unusually higher or lower level than some predetermined "routine maintenance" level. The individual ship profiles do not include standard deviations.

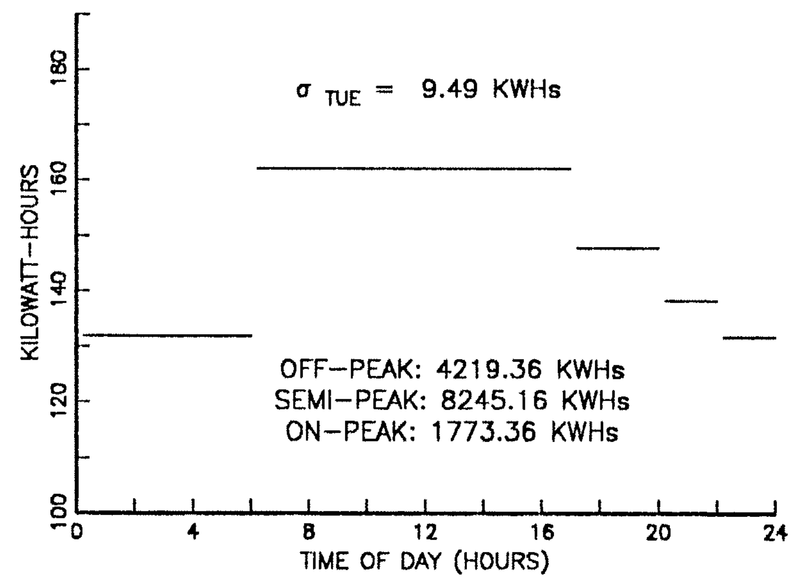
Finally, ship commanders can use the following graphs to gauge their own ship's level of consumption with that of a similar ship or appropriate class profile. The ships evaluated in this study did not have onboard KWH meters which would allow them to compare directly. However, since a ship's power factor is relatively stable (re: Appendix B), then a ship's KW meter readings could be divided by four to obtain an *instantaneous* KWH value. If several KW readings are taken within each 15 minute period and averaged, this would basically equate to the *accumulated* KWH readings that were used in this study.

FFG-7 CLASS CONSUMPTION PROFILES

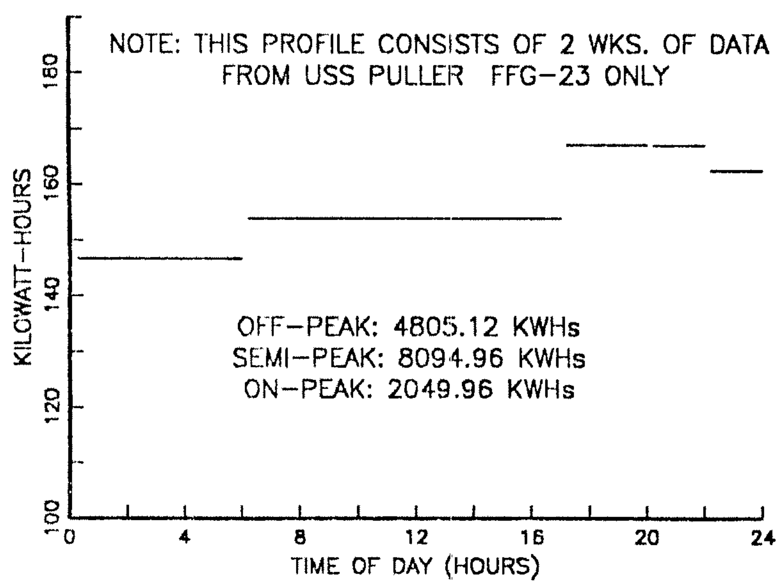
MONDAY (BILLING PERIODS 3 & 4) AVG. KWH DATA



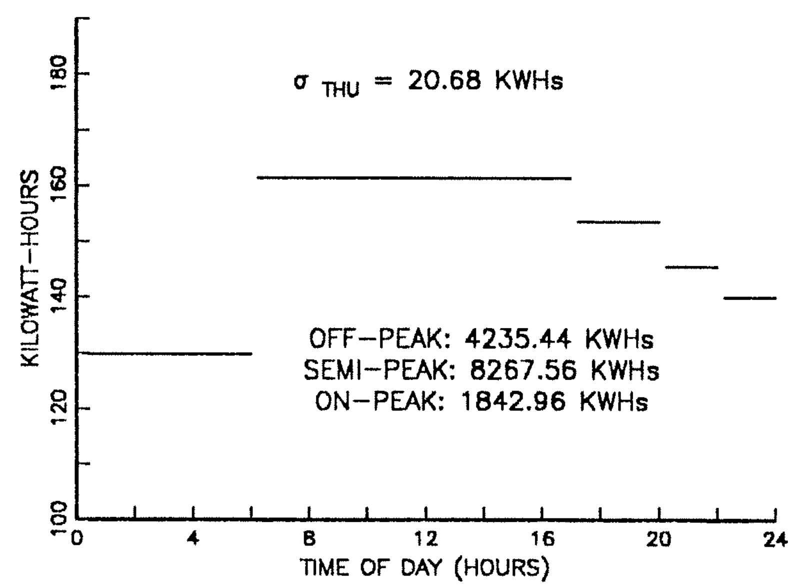
TUESDAY (BILLING PERIODS 3 & 4) AVG. KWH DATA



WEDNESDAY (BILLING PERIODS 3 & 4) AVG. KWH DATA

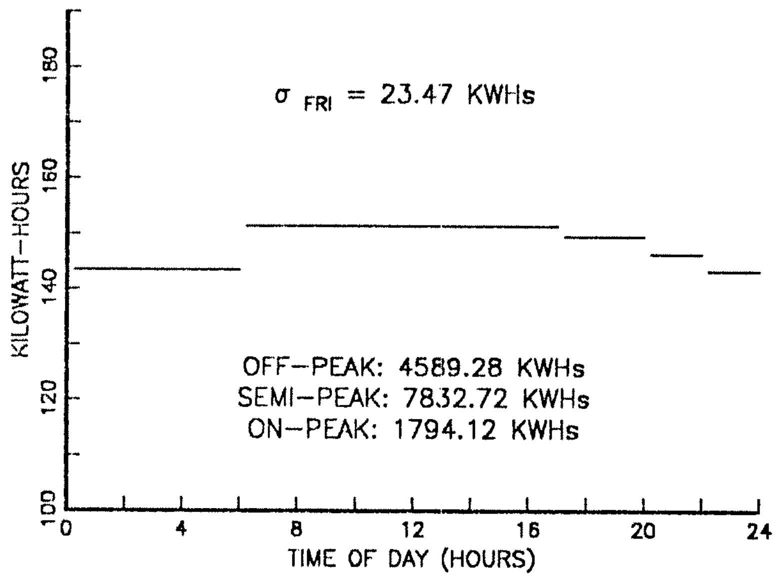


THURSDAY (BILLING PERIODS 3 & 4) AVG. KWH DATA

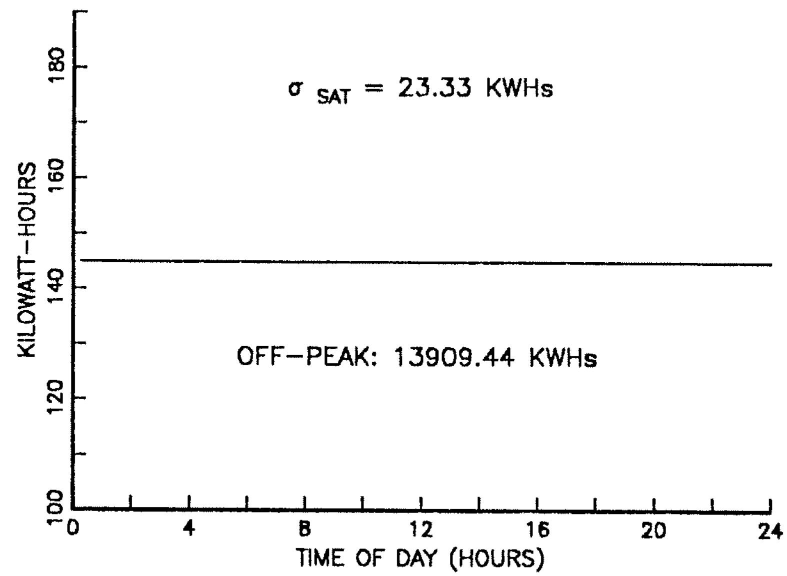


FFG-7 CLASS CONSUMPTION PROFILES

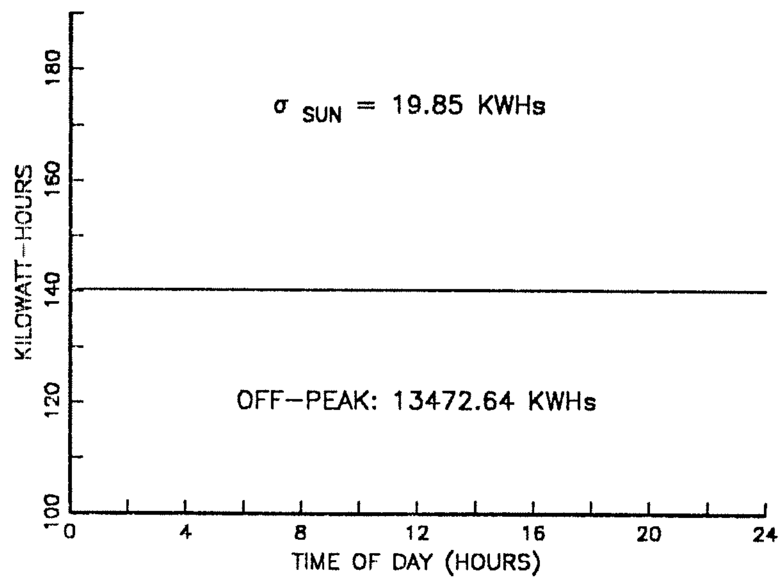
FRIDAY (BILLING PERIODS 3 & 4) AVG. KWH DATA



SATURDAY (BILLING PERIODS 3 & 4) AVG. KWH DATA

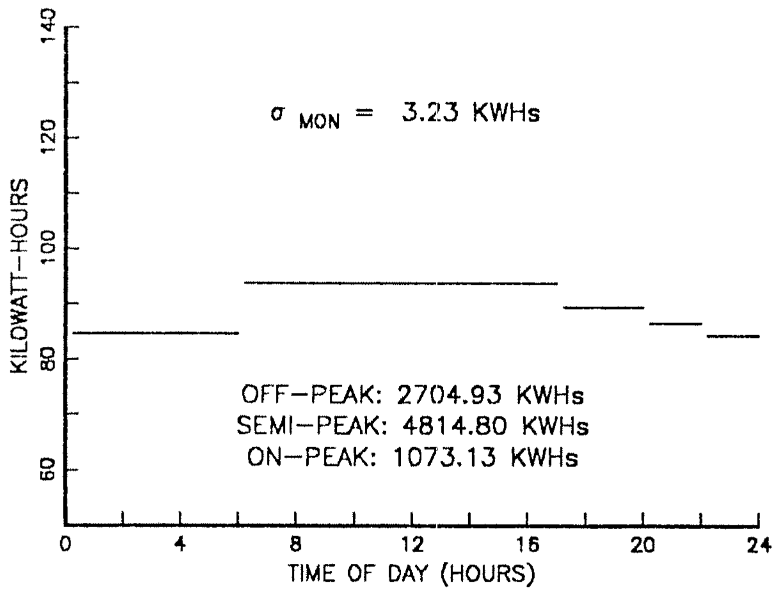


SUNDAY (BILLING PERIODS 3 & 4) AVG. KWH DATA

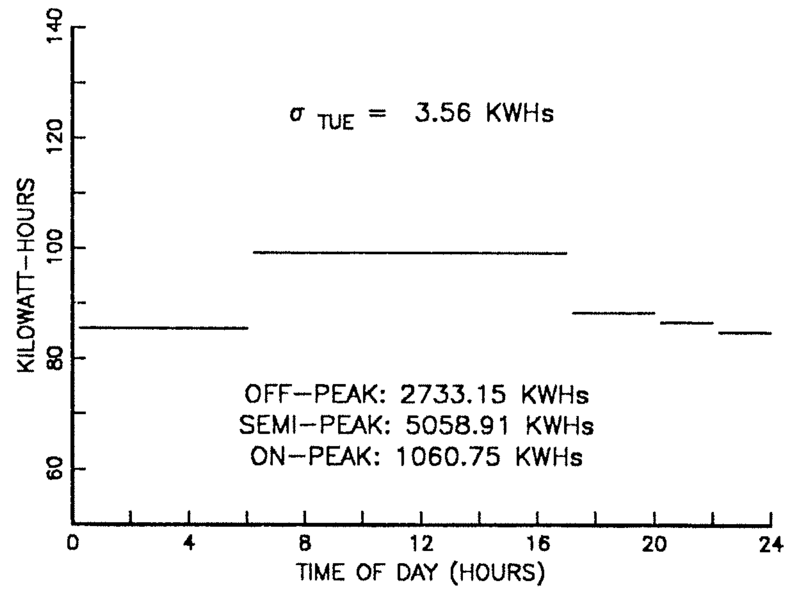


LST-1179 CLASS CONSUMPTION PROFILES

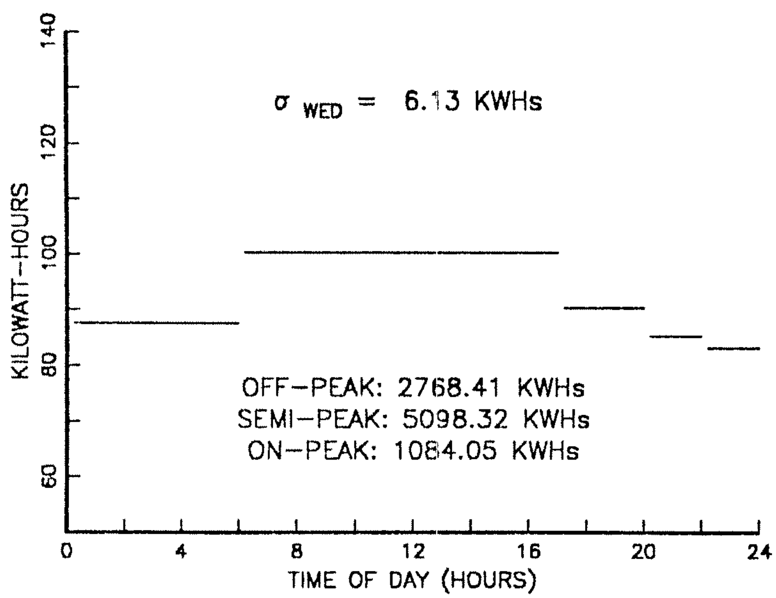
MONDAY (BILLING PERIODS 3 & 4) AVG. KWH DATA



TUESDAY (BILLING PERIODS 3 & 4) AVG. KWH DATA



WEDNESDAY (BILLING PERIODS 3 & 4) AVG. KWH DATA



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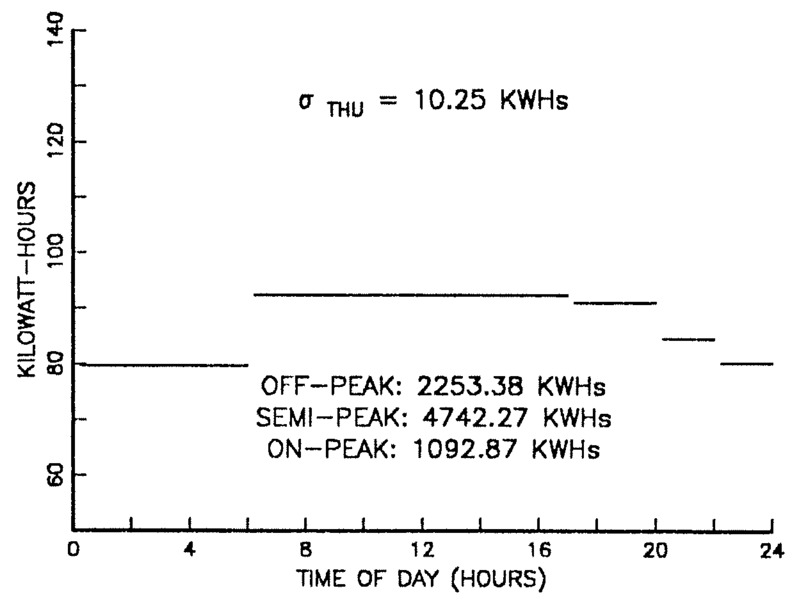

LST-1179 CLASS CONSUMPTION PROFILES

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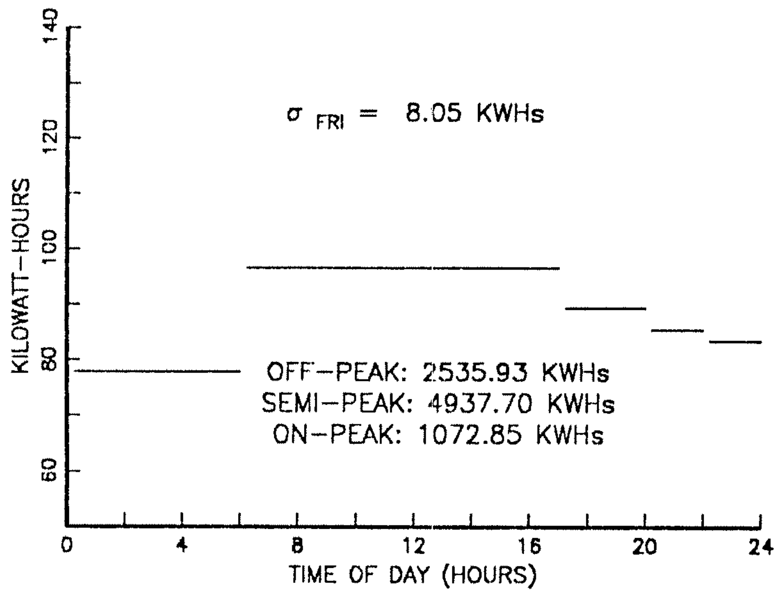

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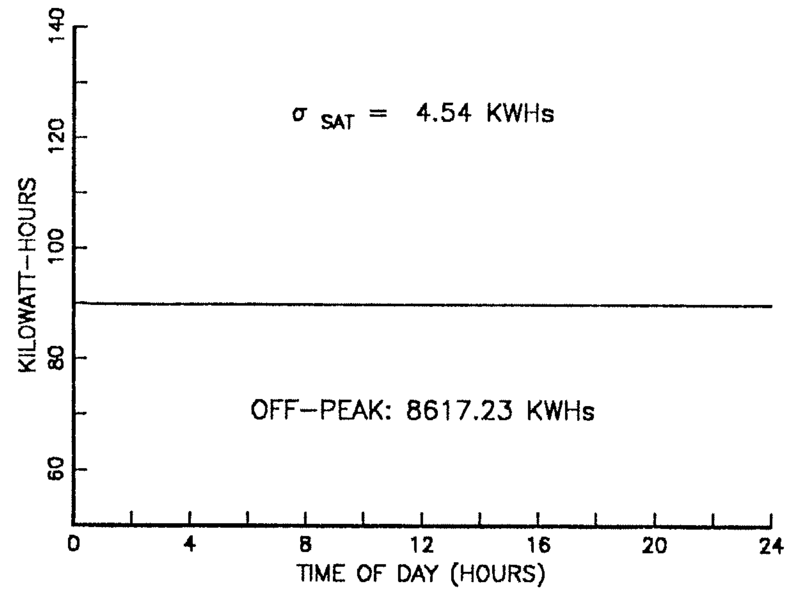

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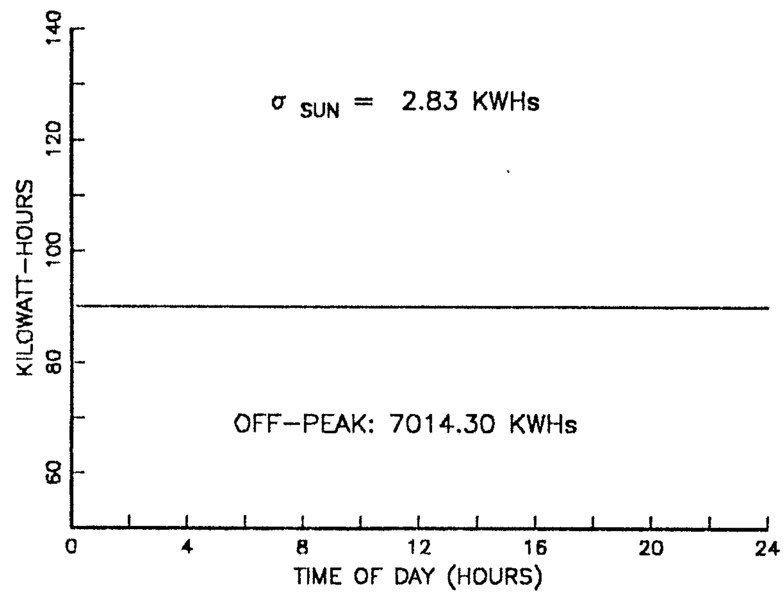
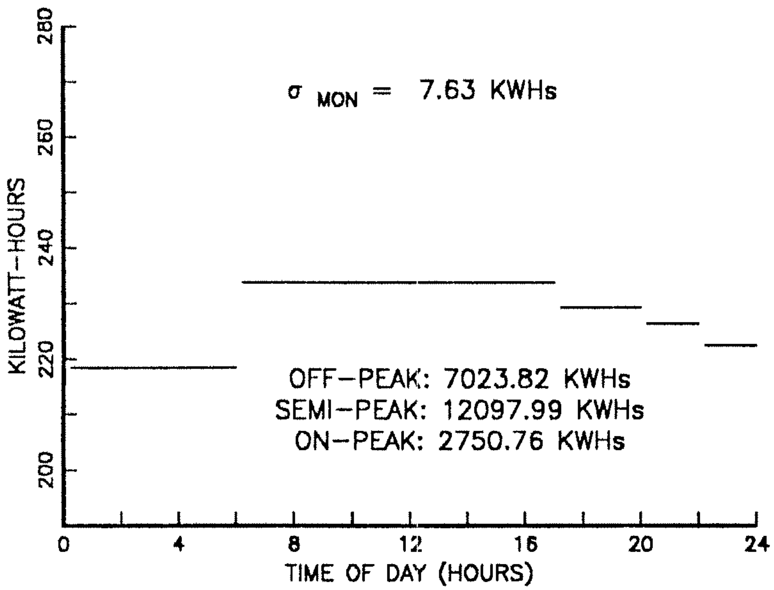


DD-963 CLASS CONSUMPTION PROFILES

MONDAY (BILLING PERIOD 5) AVG. KWH DATA



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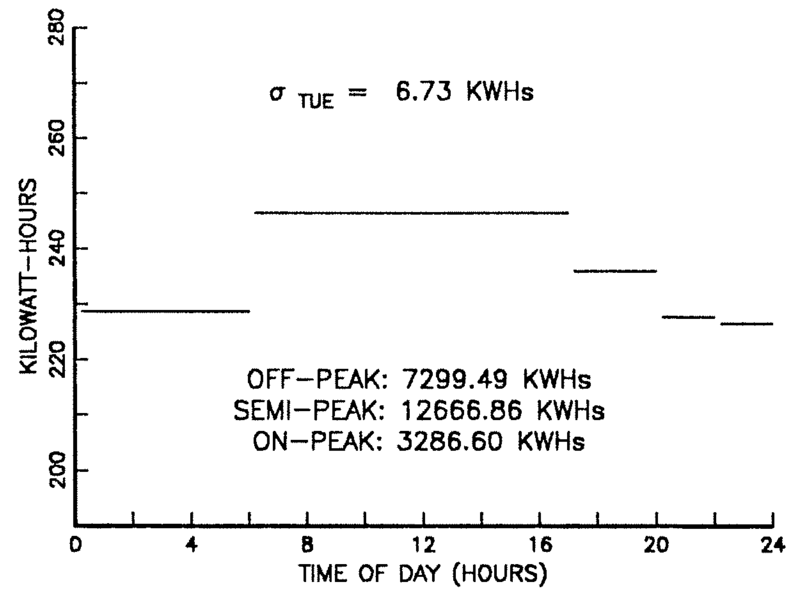

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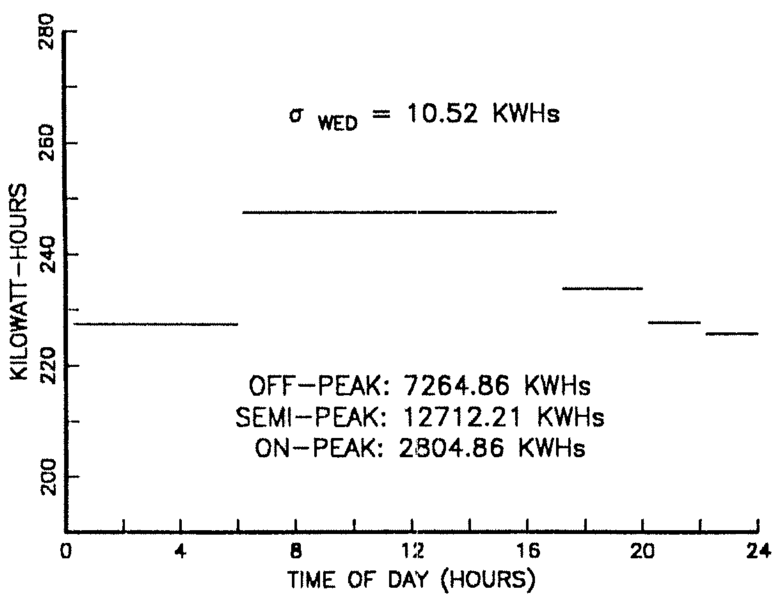

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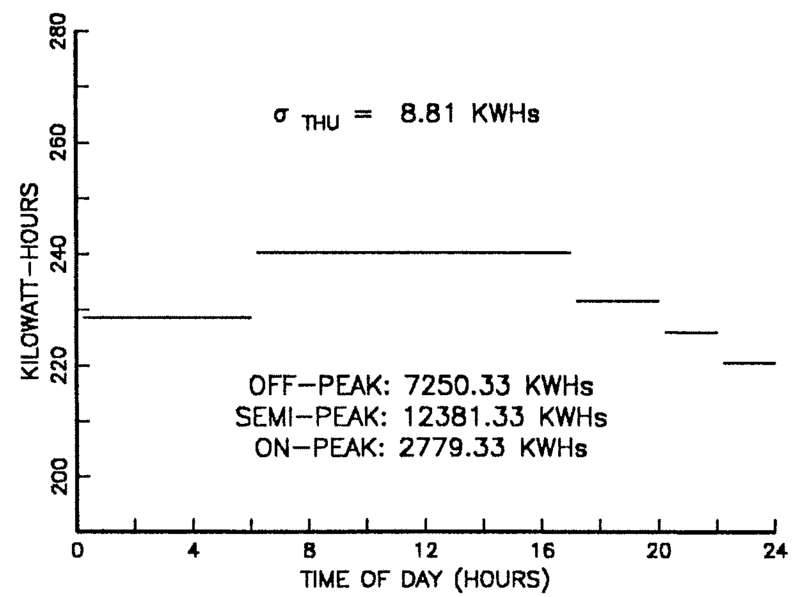

DD-963 CLASS CONSUMPTION PROFILES

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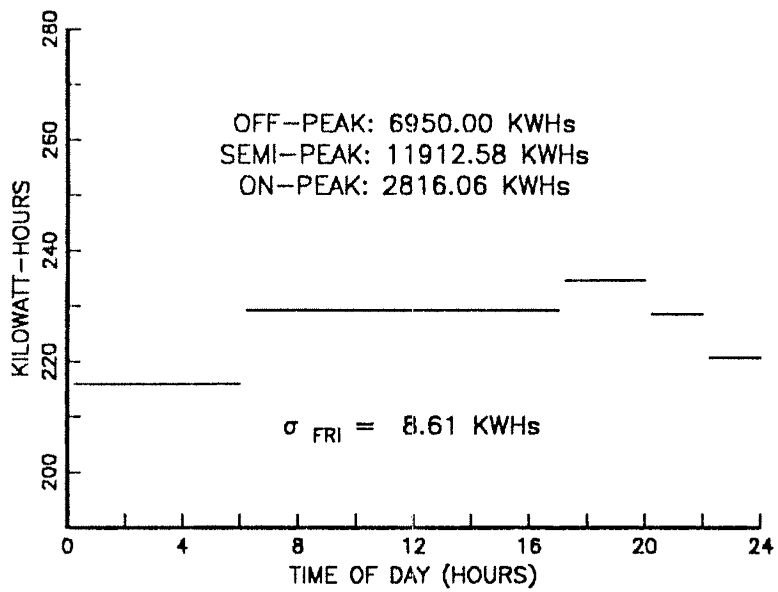

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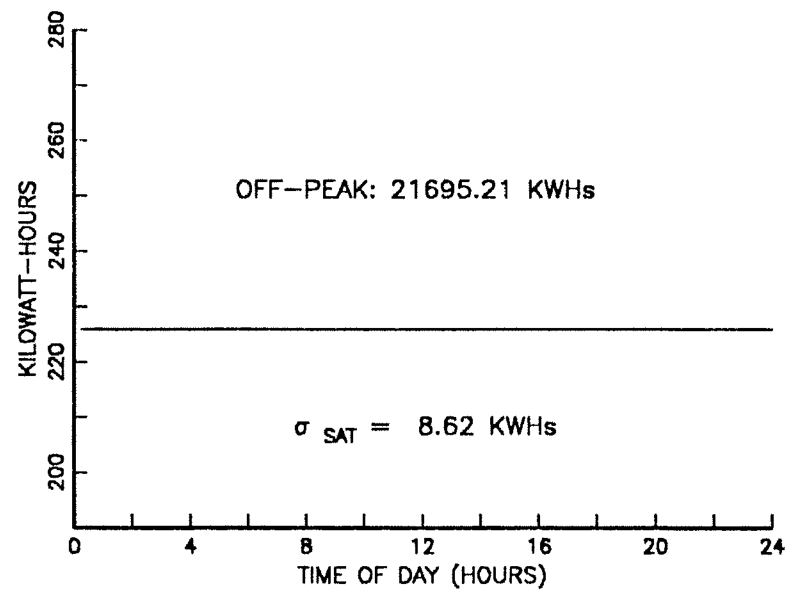

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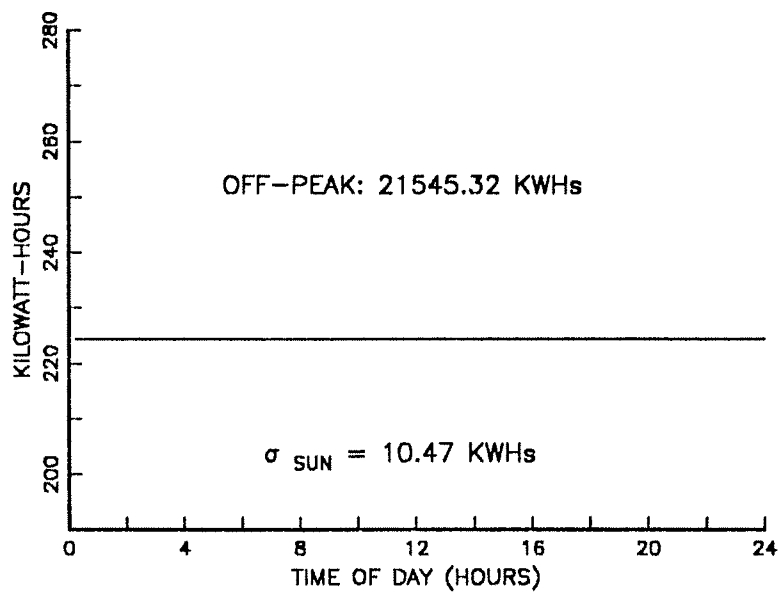

DD-963 CLASS CONSUMPTION PROFILES

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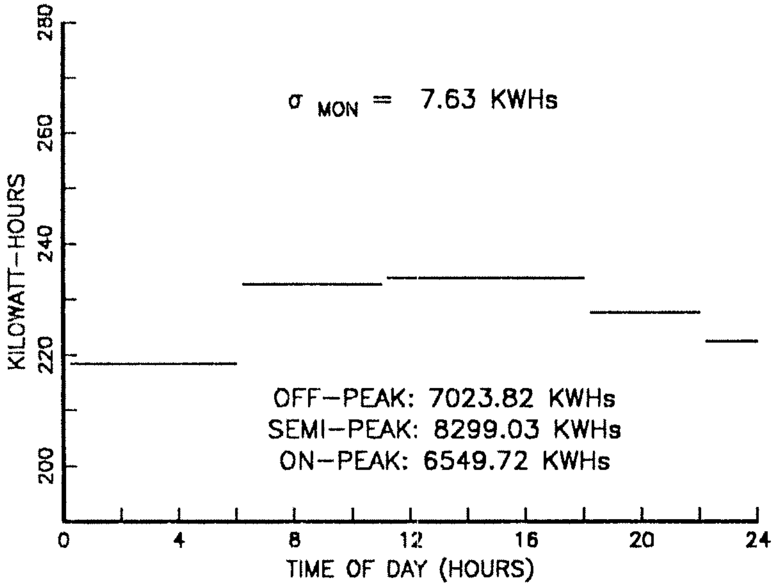

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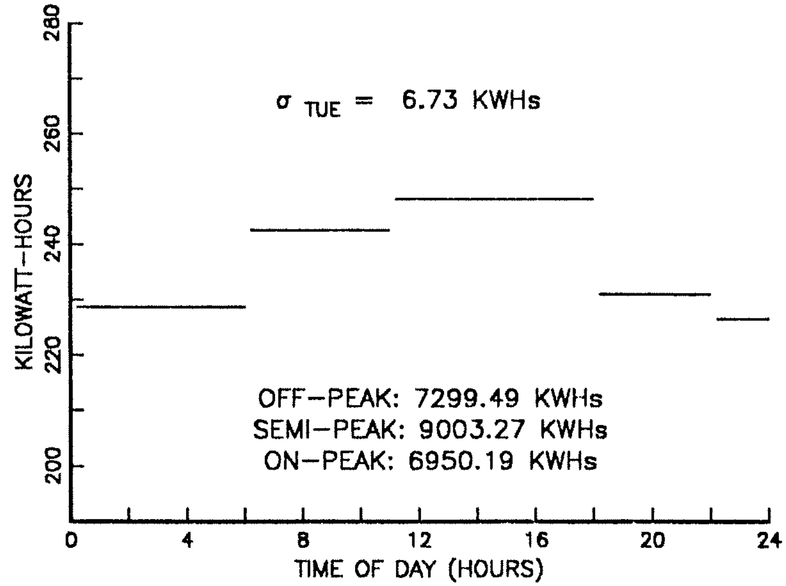

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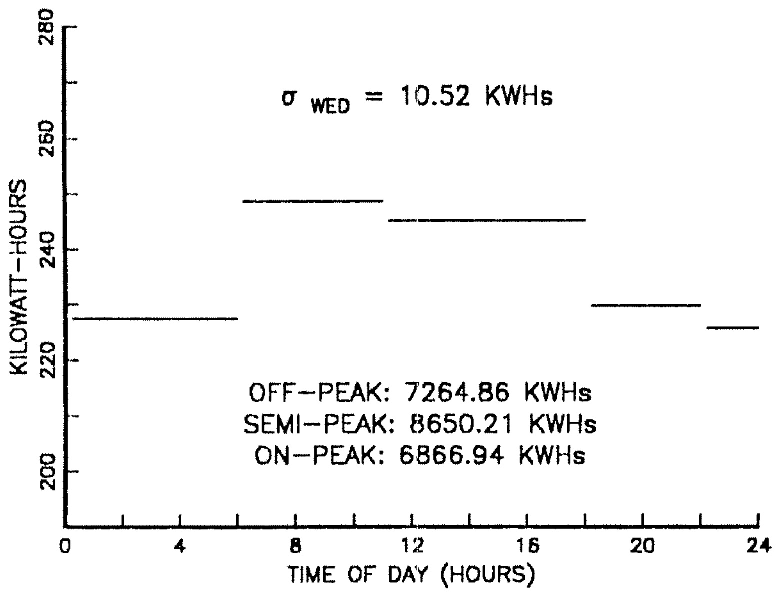

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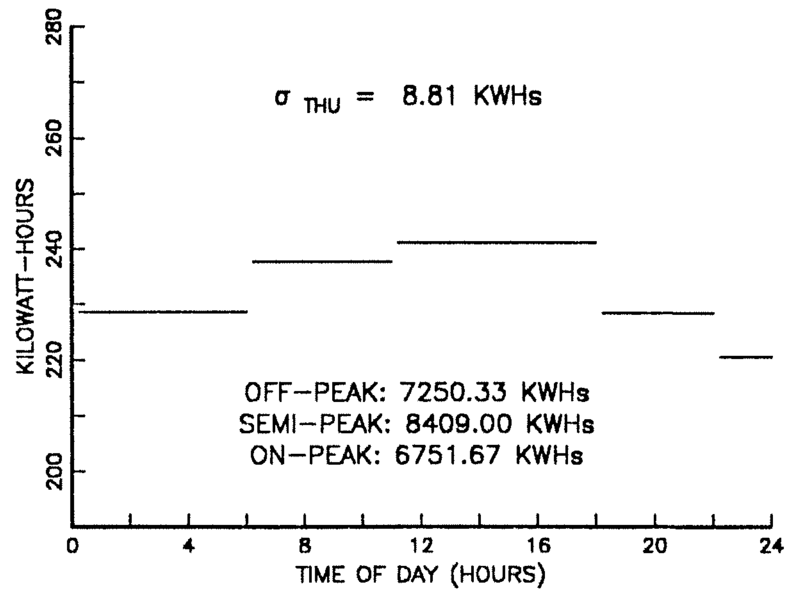

DD-963 CLASS CONSUMPTION PROFILES

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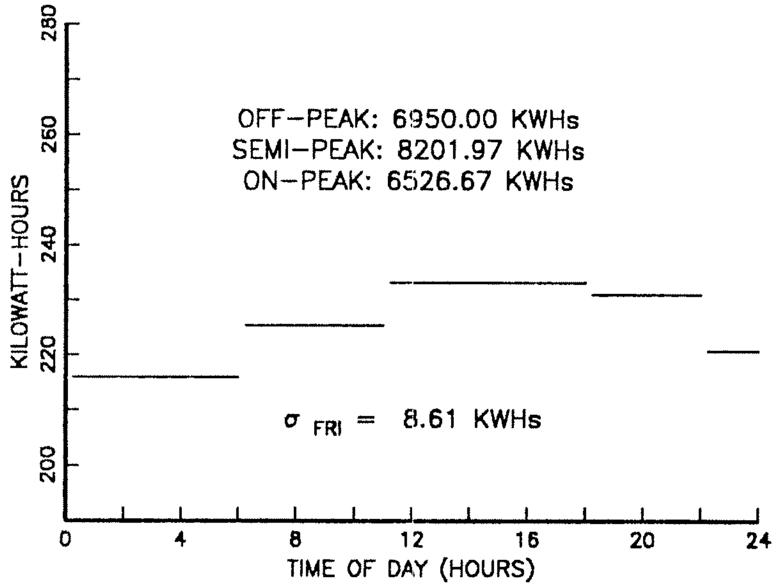

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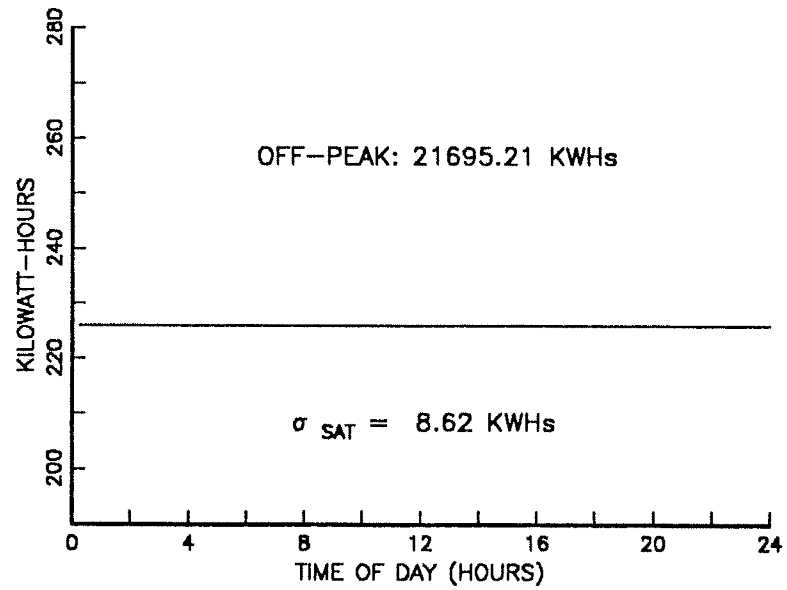

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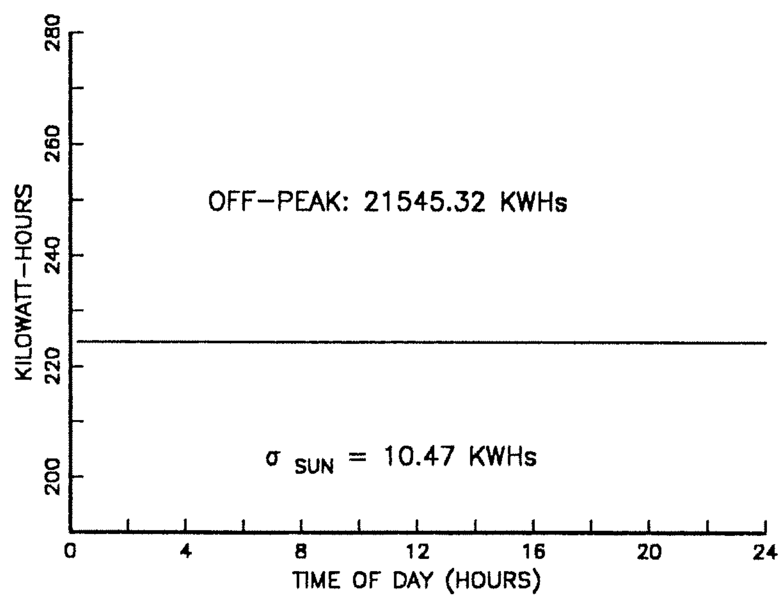

USS BARBEY (FF-1088) CONSUMPTION PROFILES

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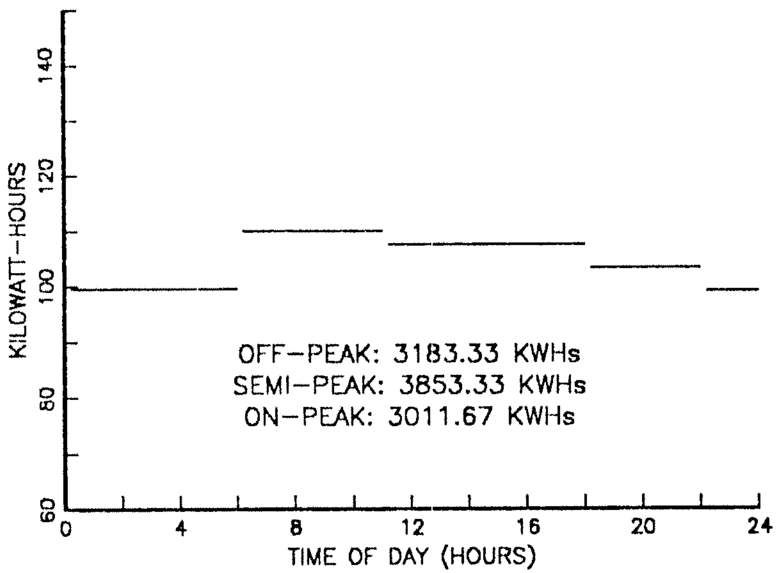

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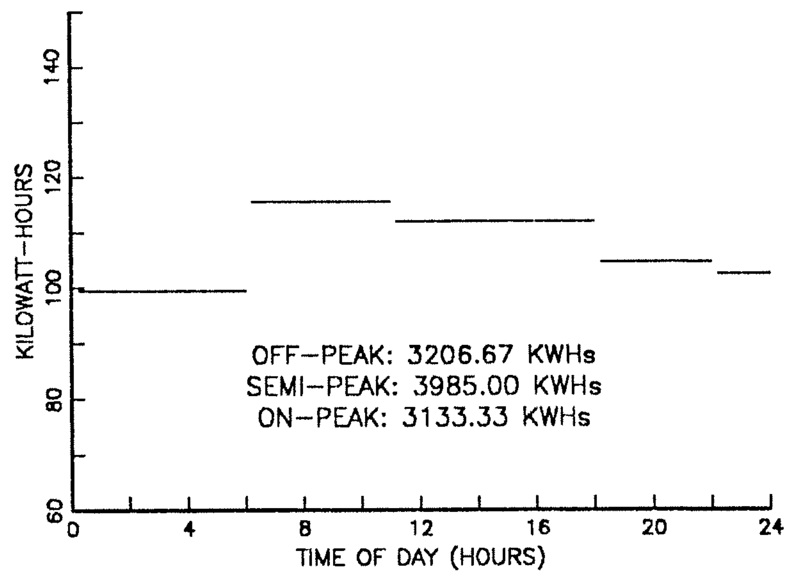

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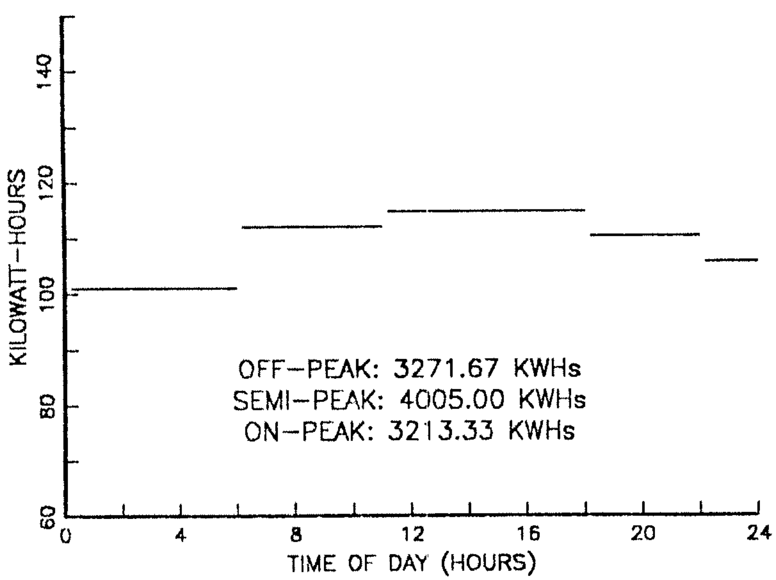

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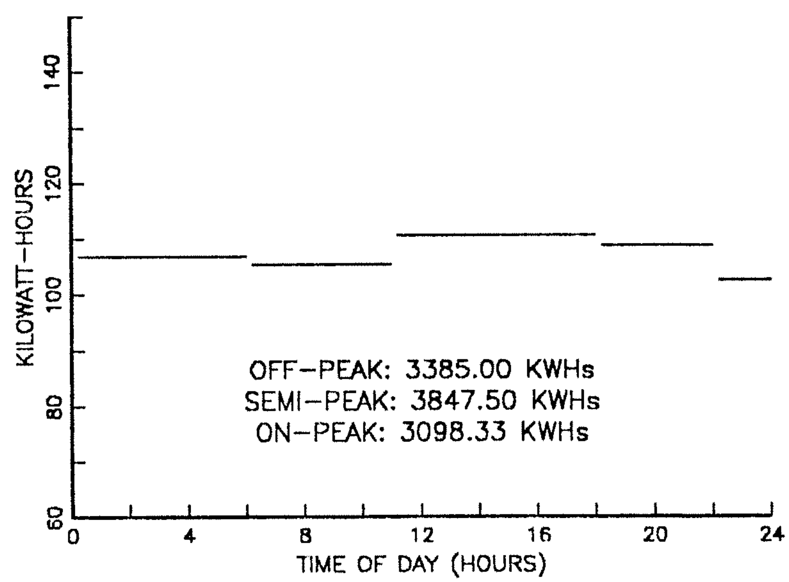

USS BARBEY (FF-1088) CONSUMPTION PROFILES

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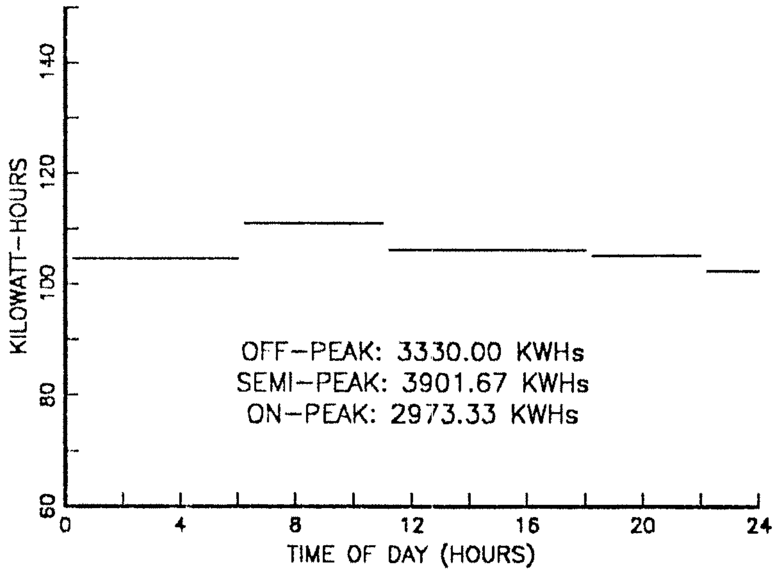

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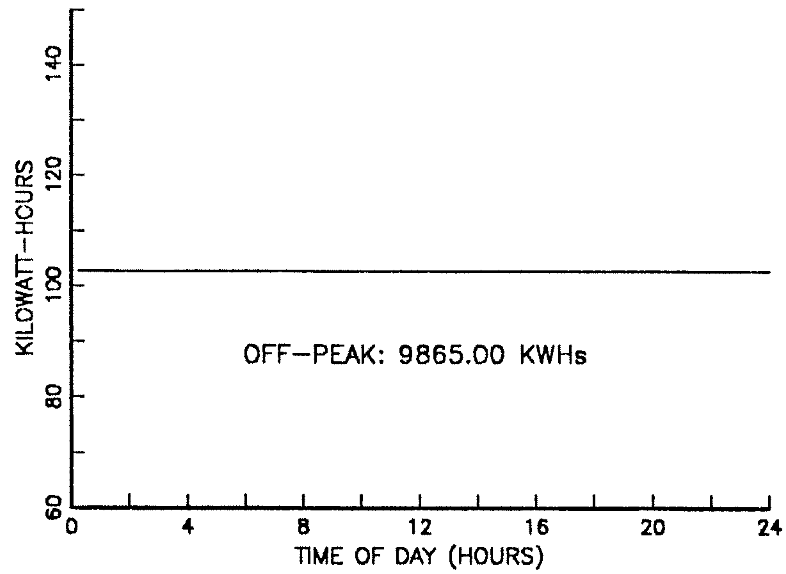

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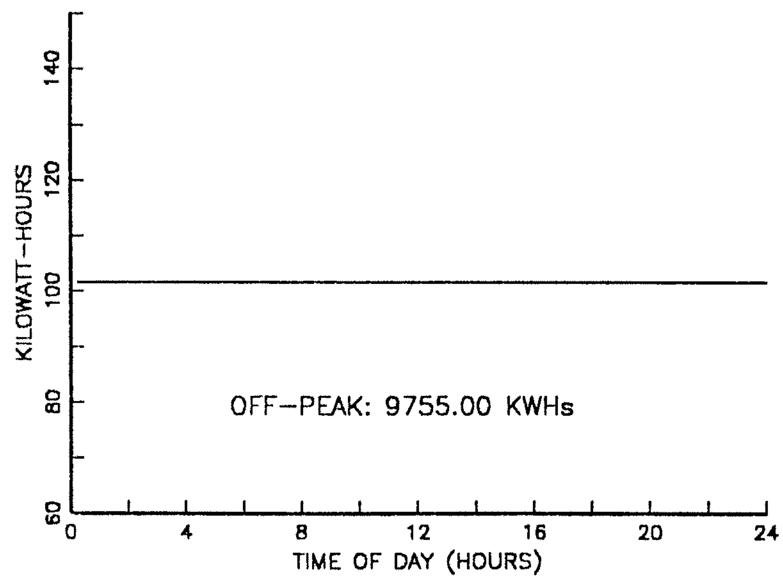

USS O'BRIEN (DD-975) CONSUMPTION PROFILES

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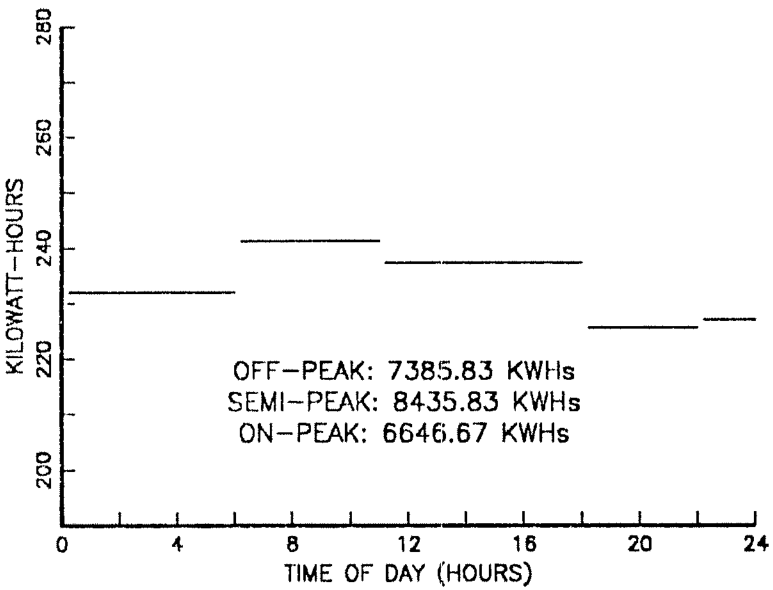

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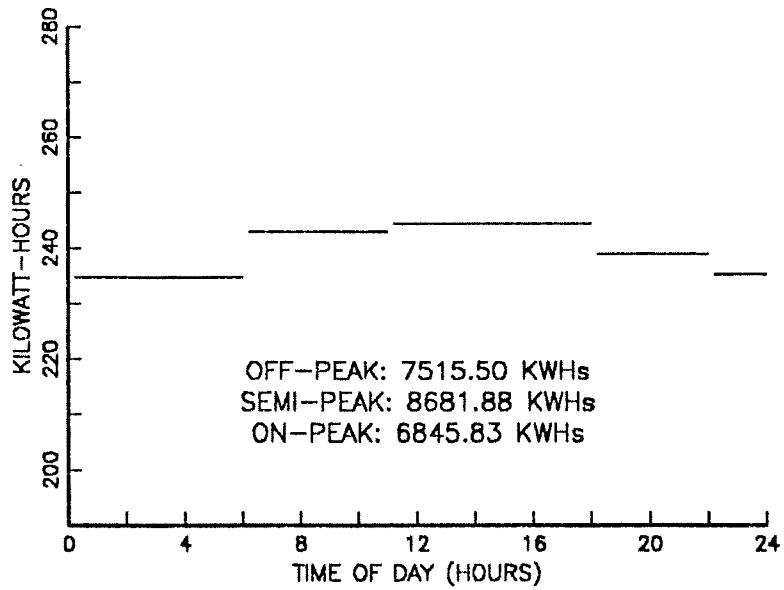

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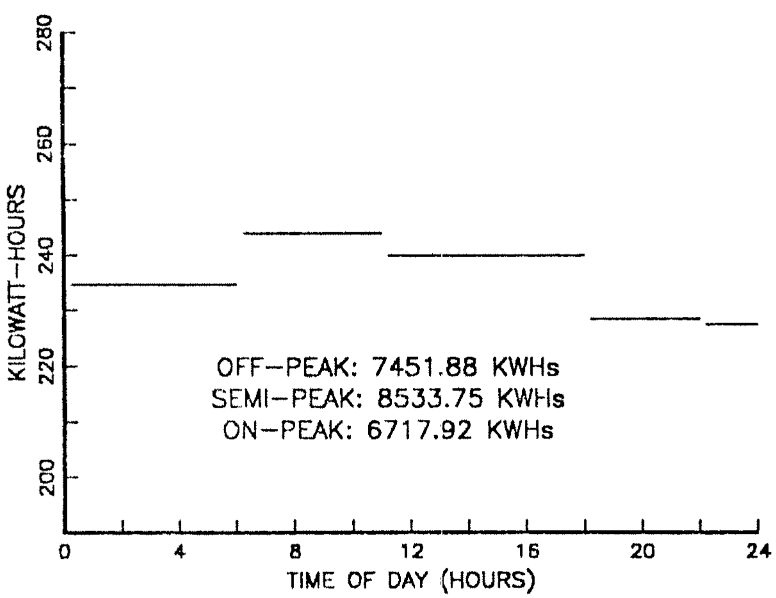

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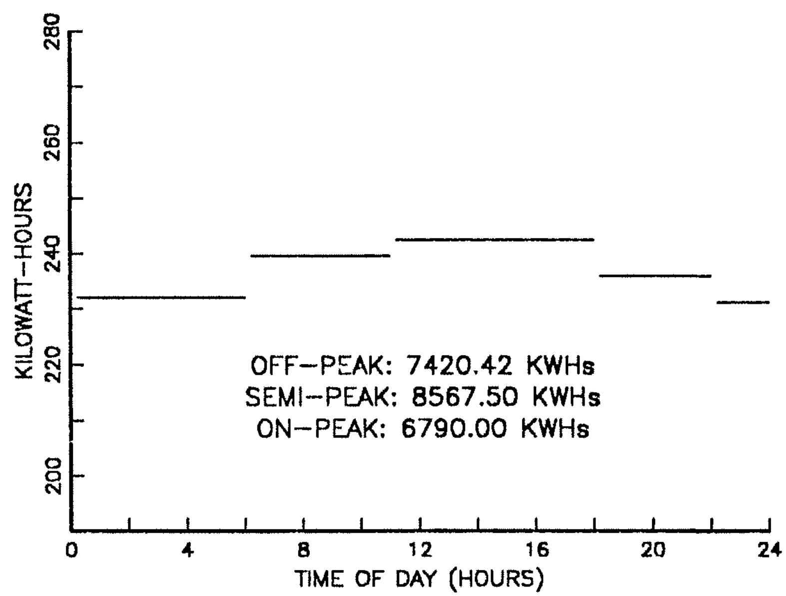

USS O'BRIEN (DD-975) CONSUMPTION PROFILES

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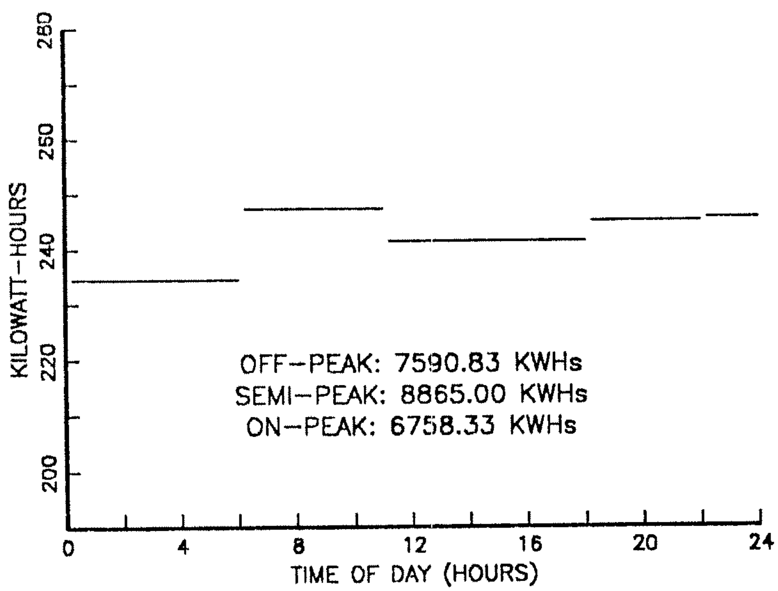

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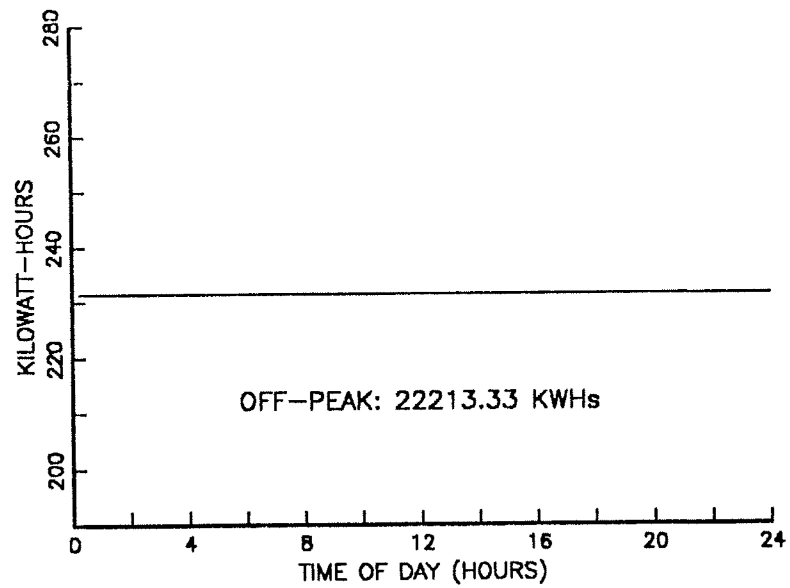

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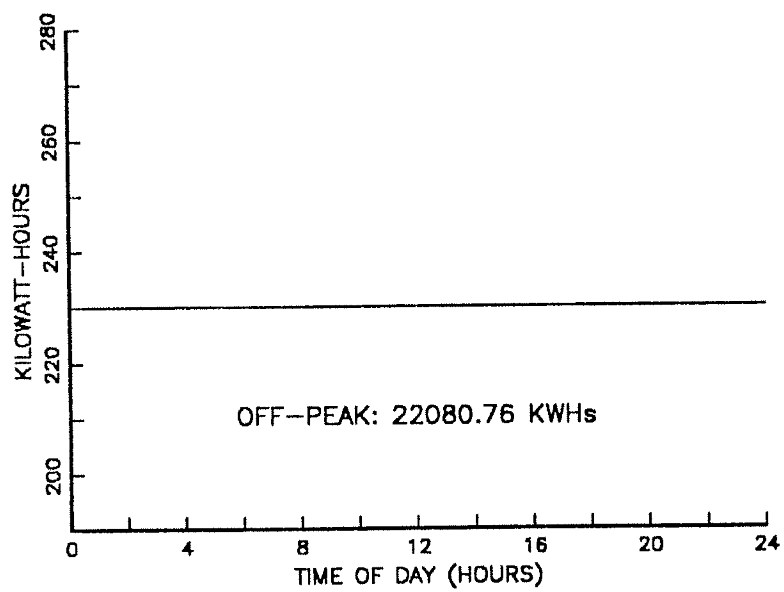
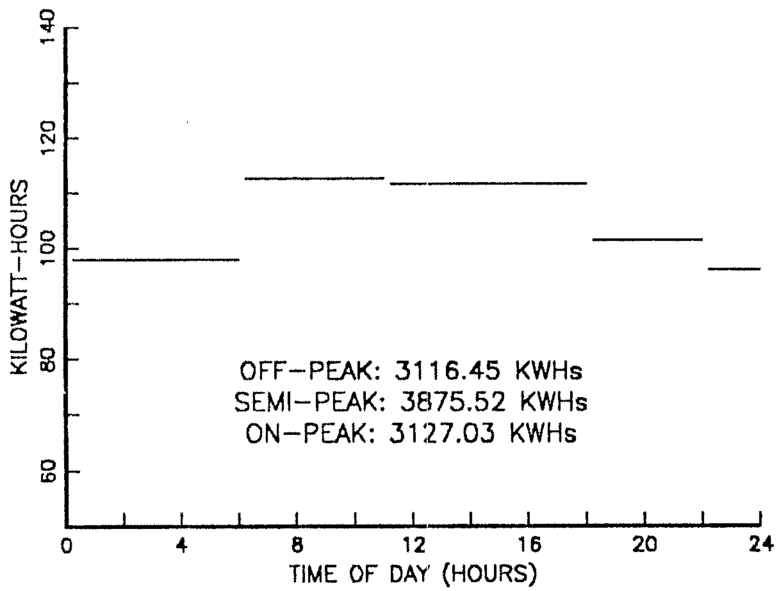


USS PEORIA (LST-1183) CONSUMPTION PROFILES

MONDAY (BILLING PERIOD 7) AVG. KWH DATA



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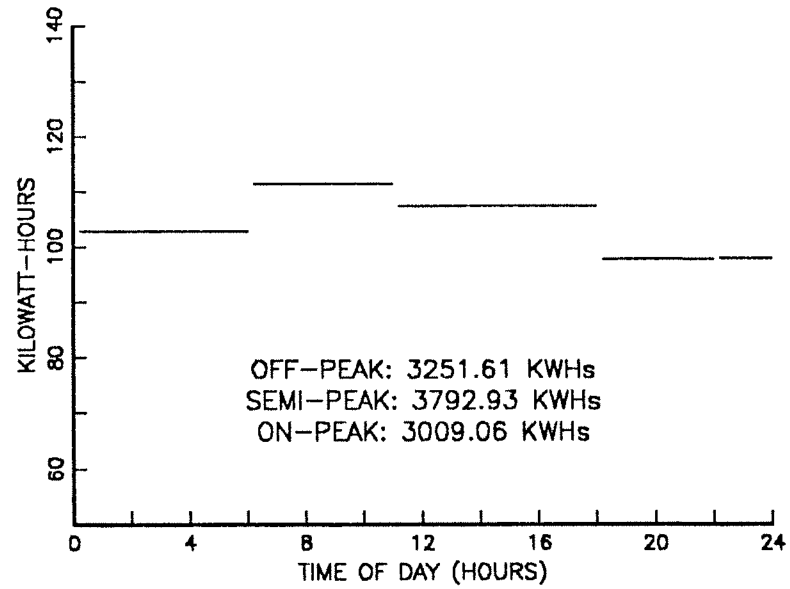

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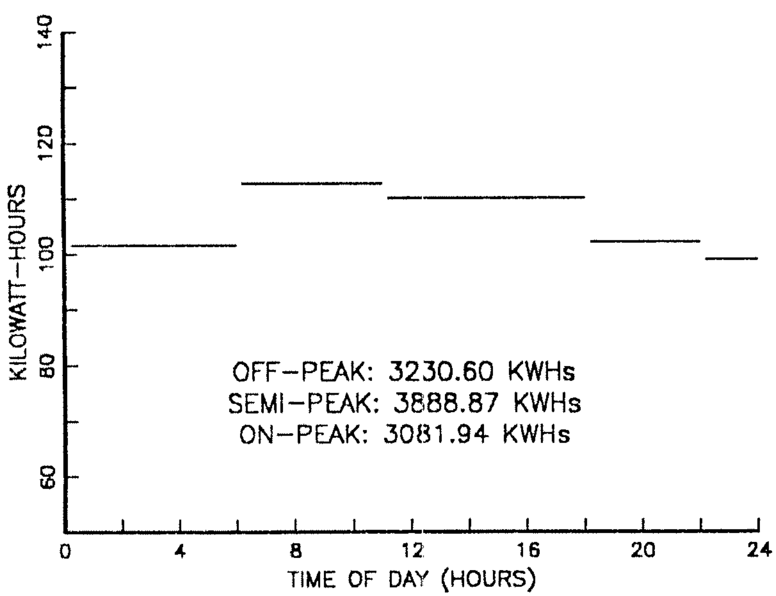

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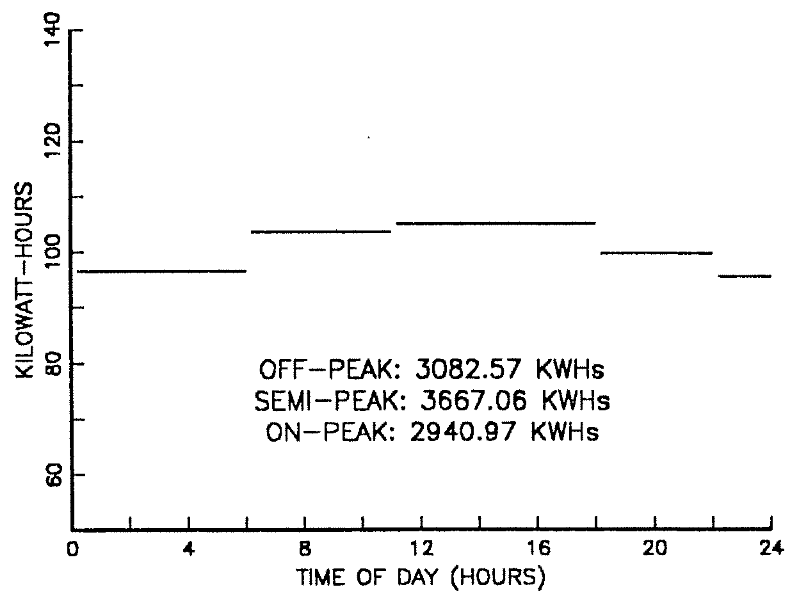

USS PEORIA (LST-1183) CONSUMPTION PROFILES

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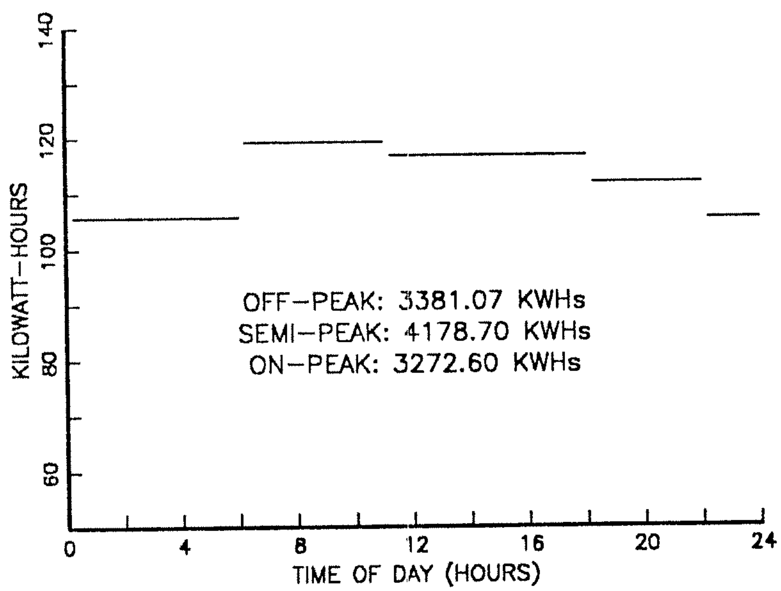

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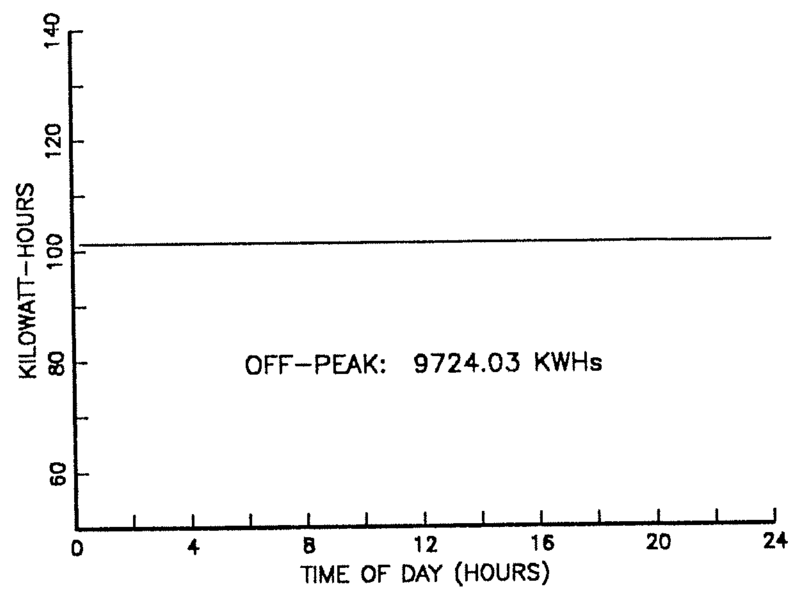

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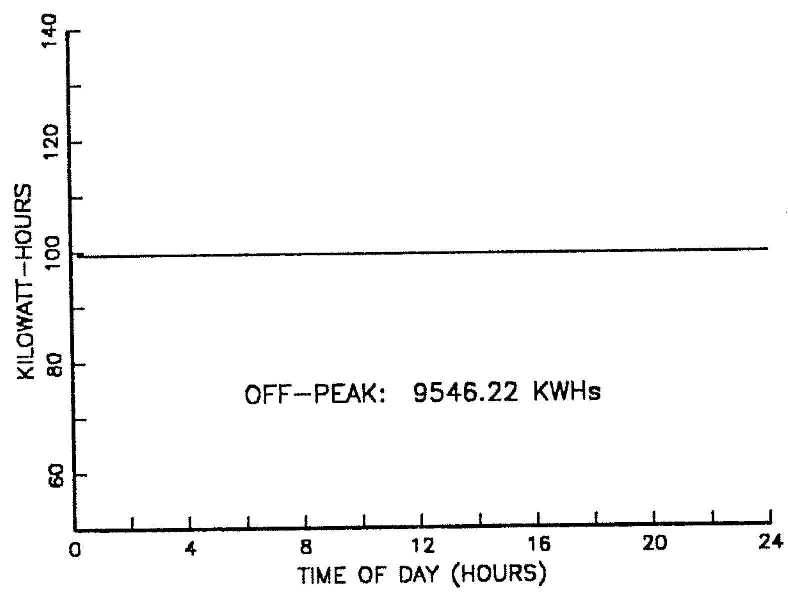
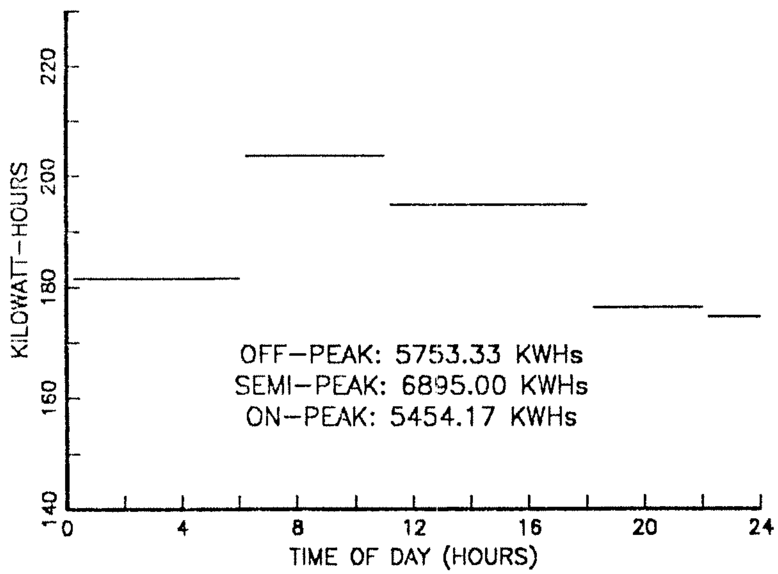
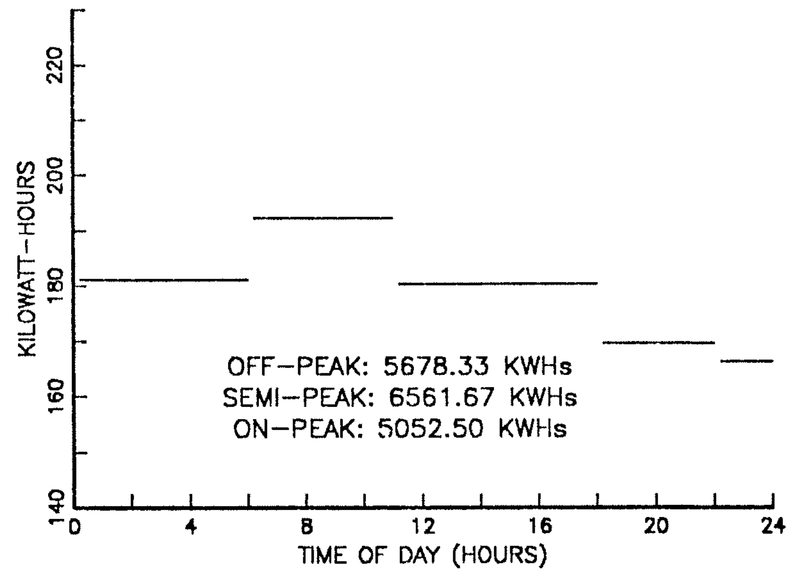


USS THACH (FFG-43) CONSUMPTION PROFILES

MONDAY (BILLING PERIOD 7) AVG. KWH DATA



TUESDAY (BILLING PERIOD 7) AVG. KWH DATA



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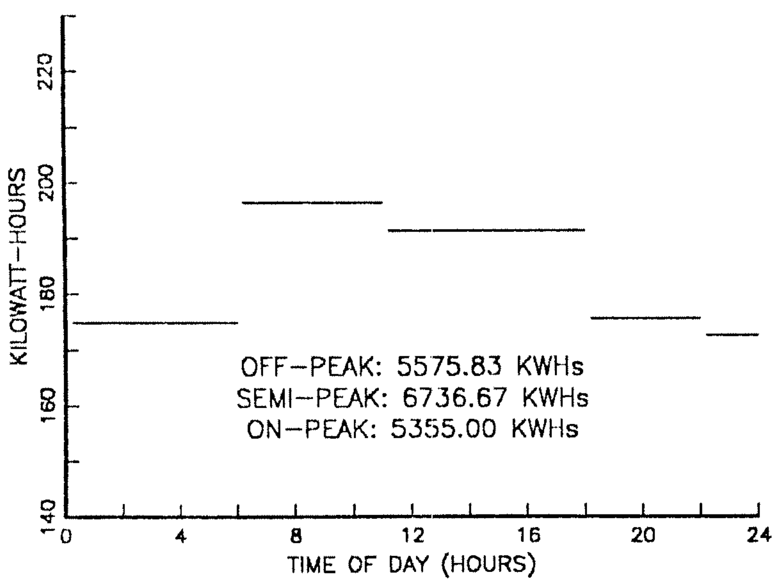

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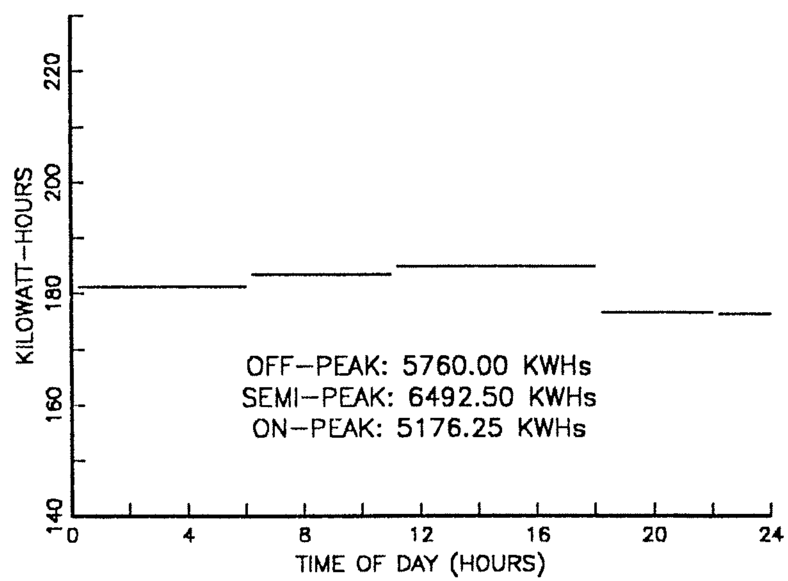

USS THACH (FFG-43) CONSUMPTION PROFILES

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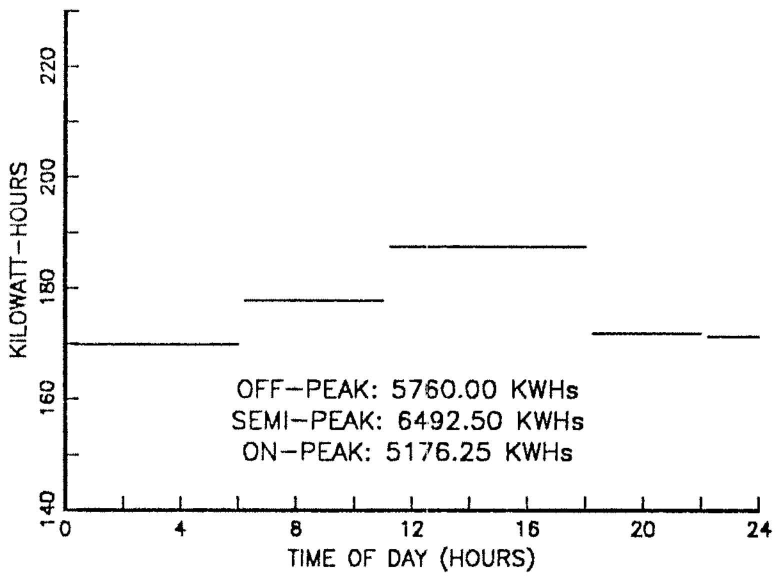

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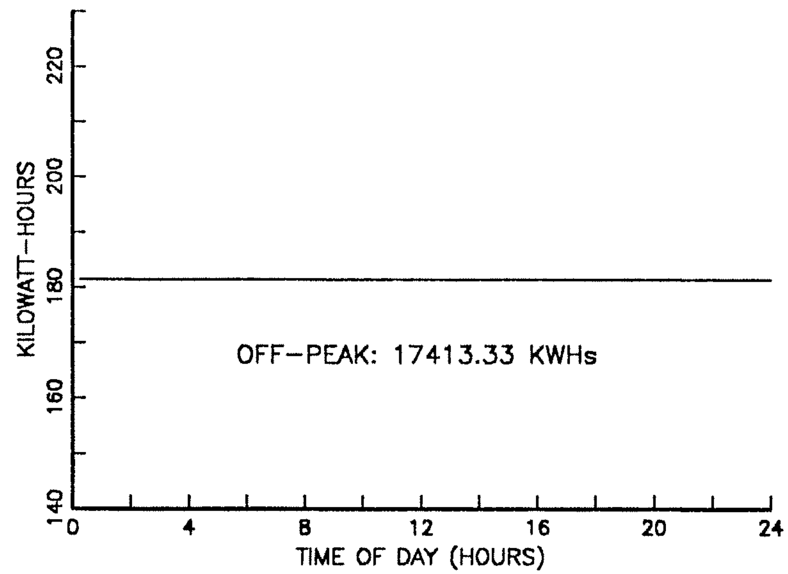

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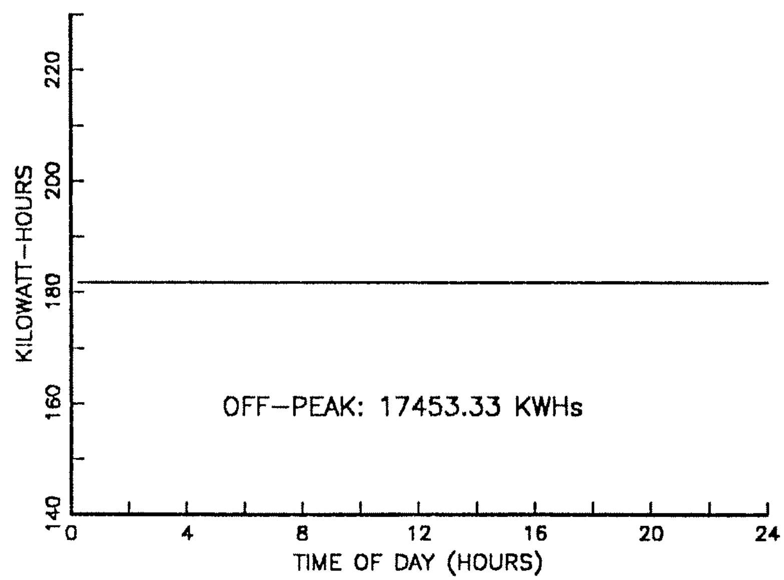

USS DULUTH (LPD-6) CONSUMPTION PROFILES

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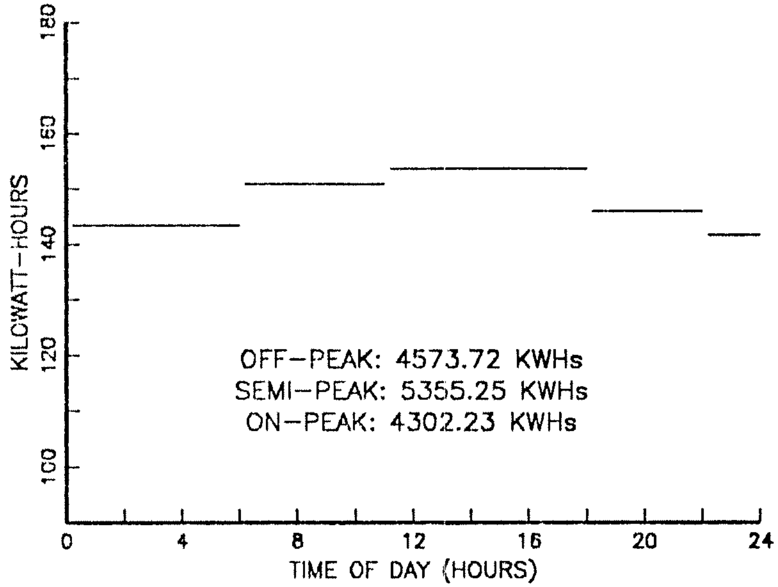

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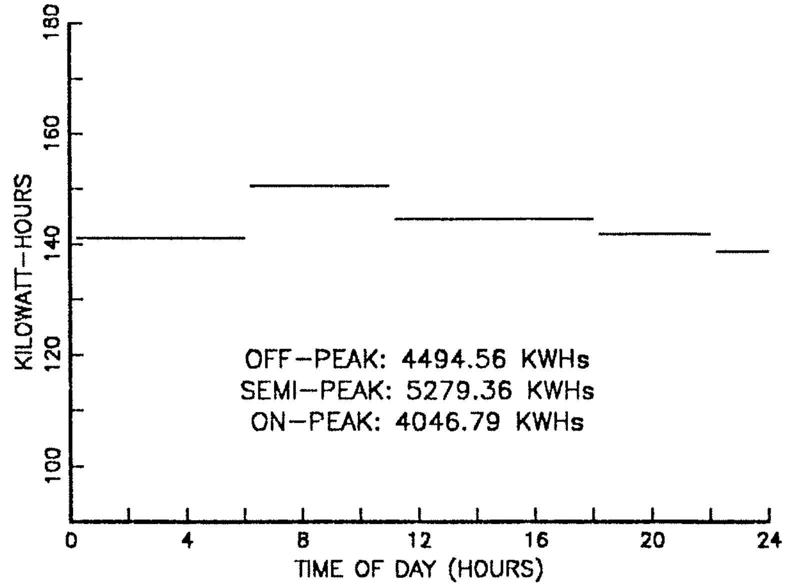

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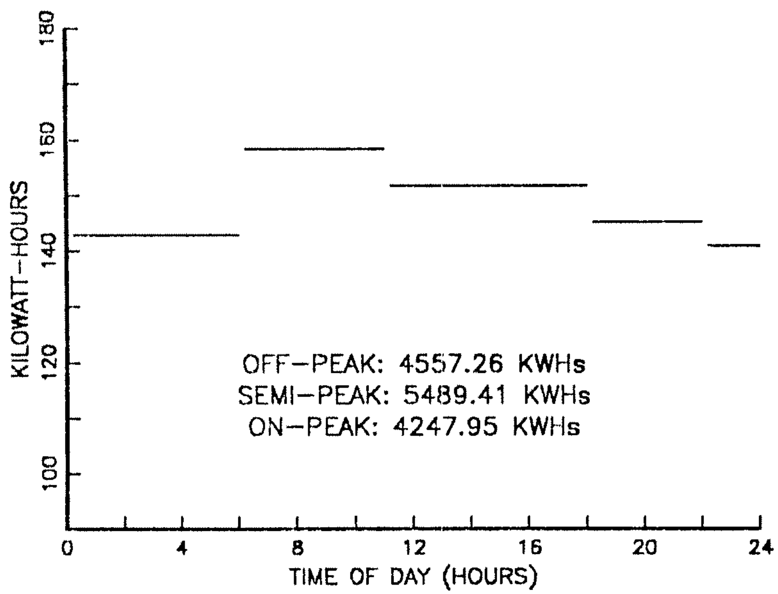

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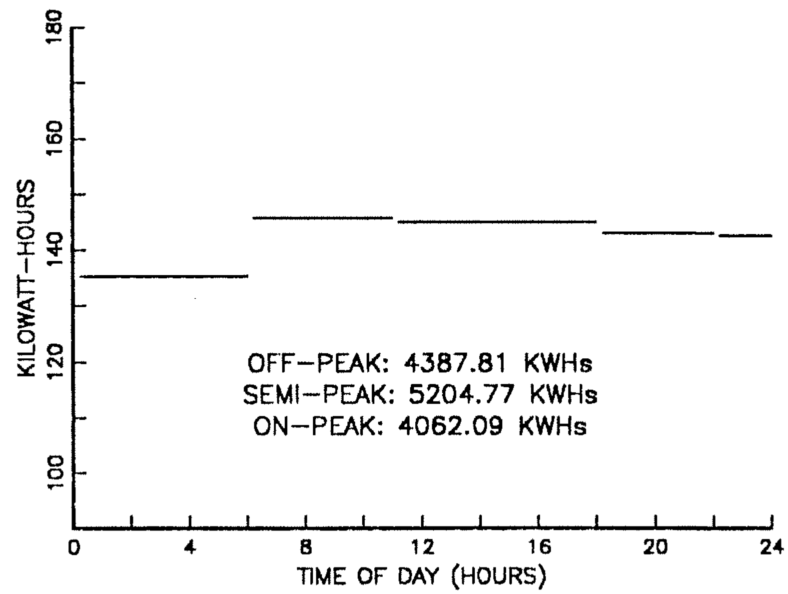

USS DULUTH (LPD-6) CONSUMPTION PROFILES

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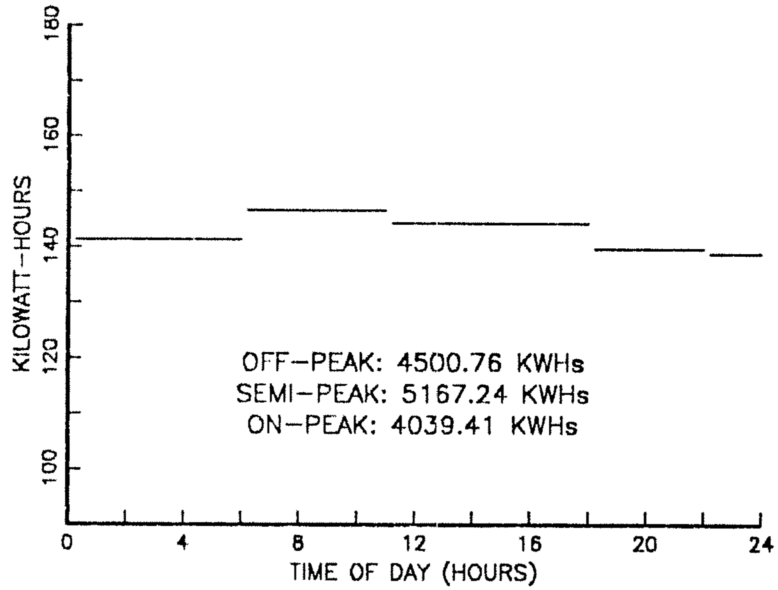

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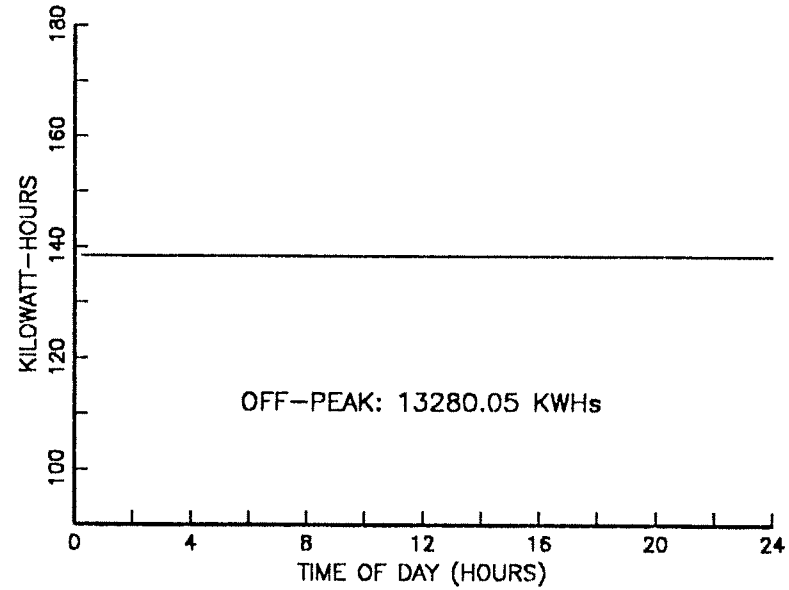

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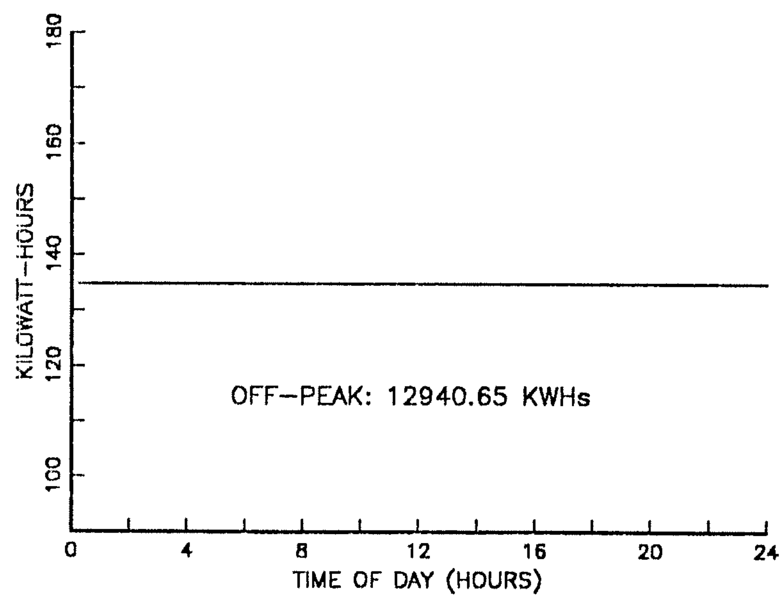
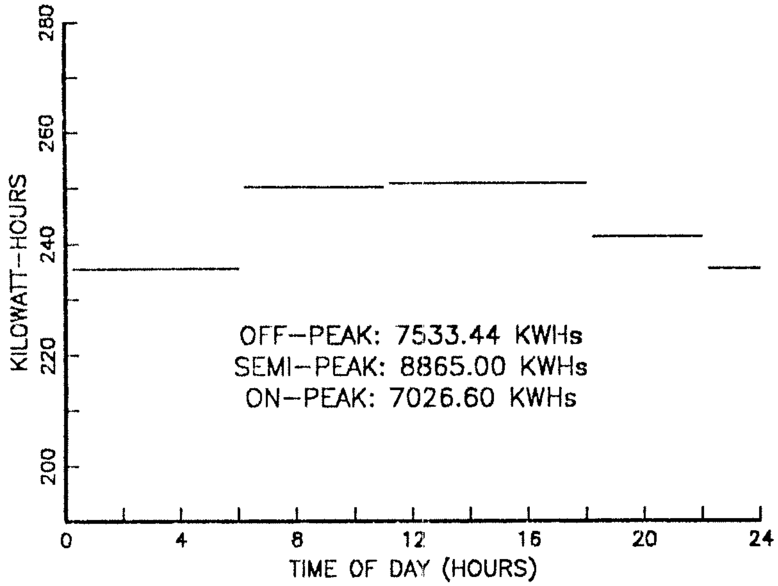


USS HILL (DD-986) CONSUMPTION PROFILES

MONDAY (BILLING PERIOD 9) AVG. KWH DATA



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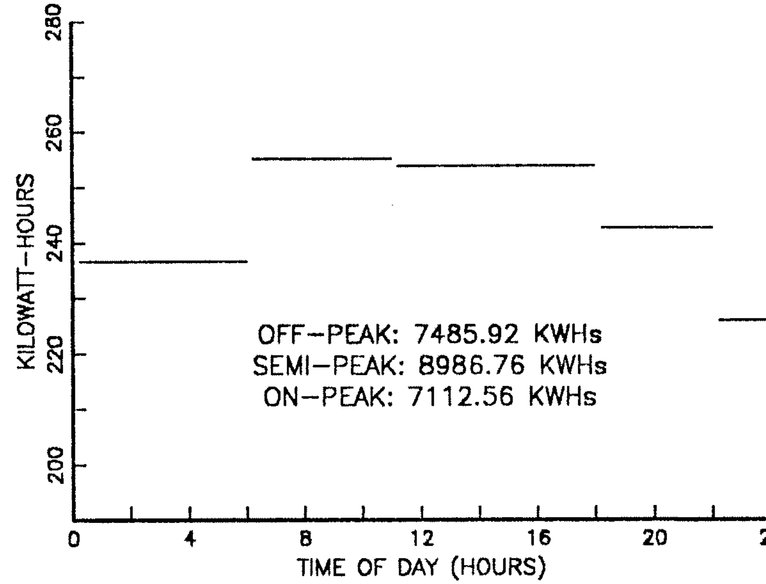

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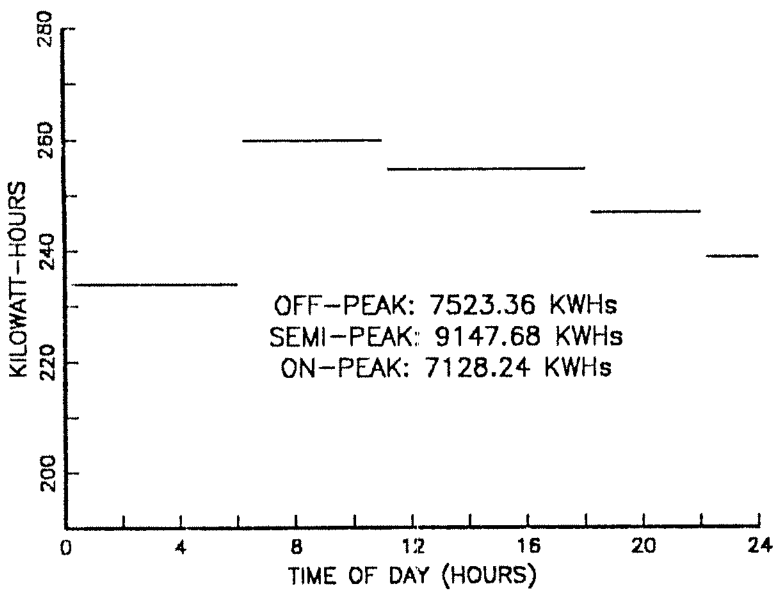

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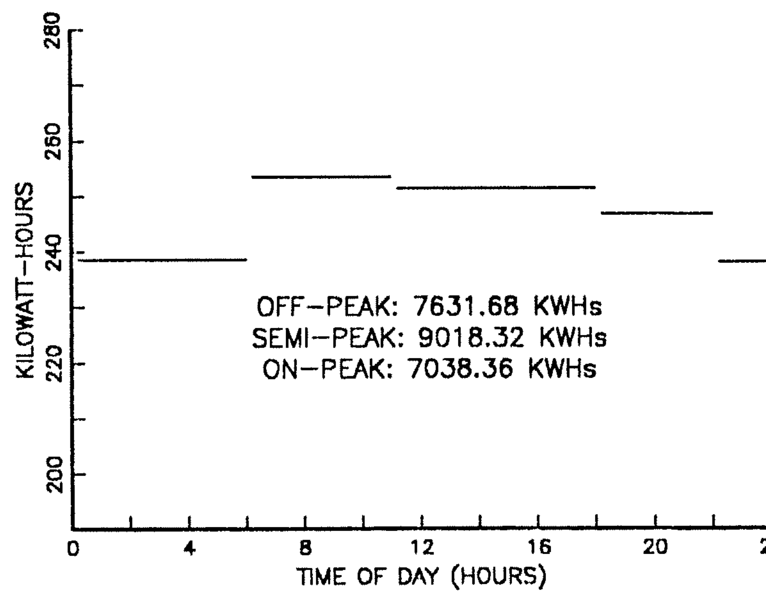

USS HILL (DD-986) CONSUMPTION PROFILES

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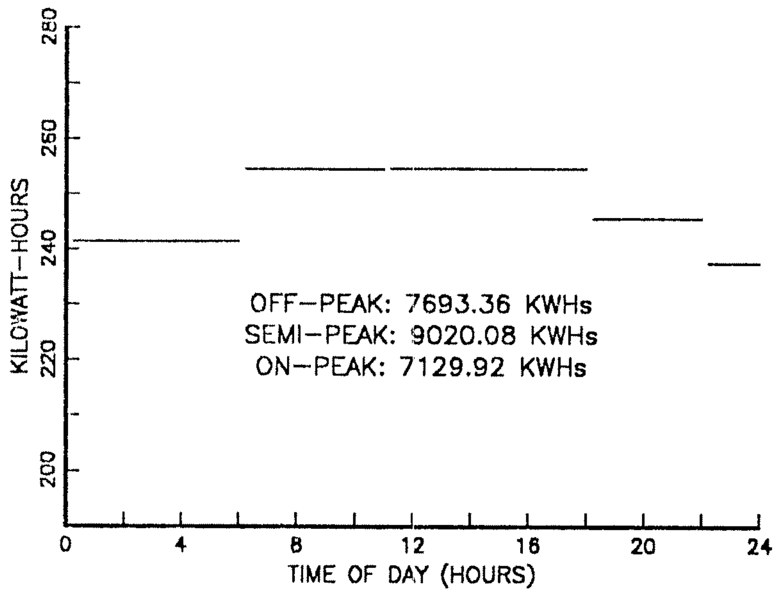

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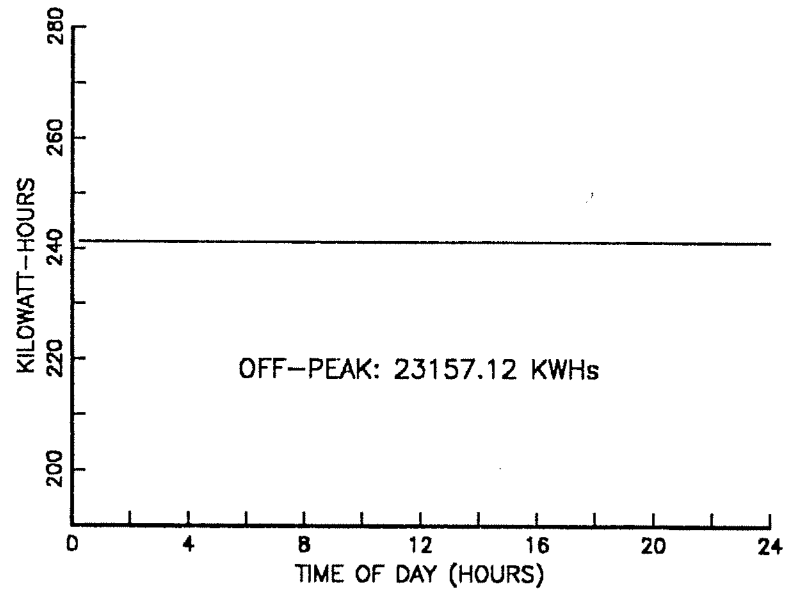

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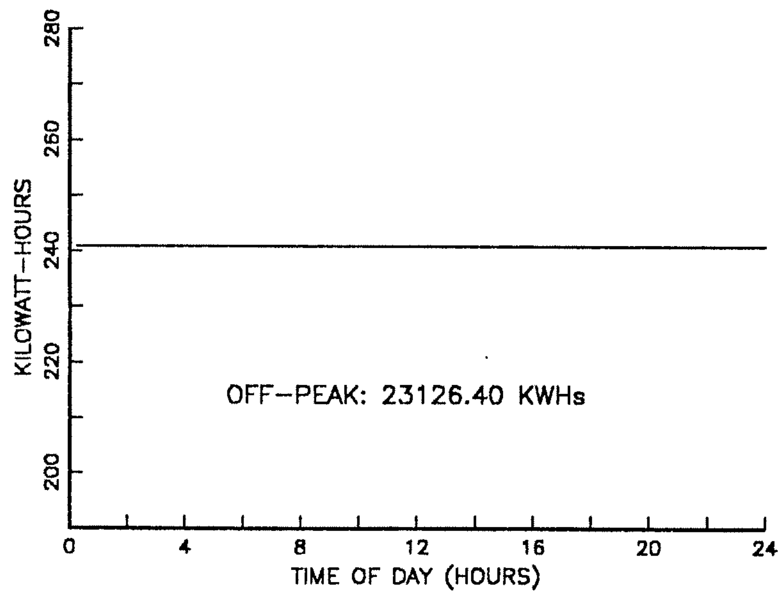

USS LEAHY (CG-16) CONSUMPTION PROFILES

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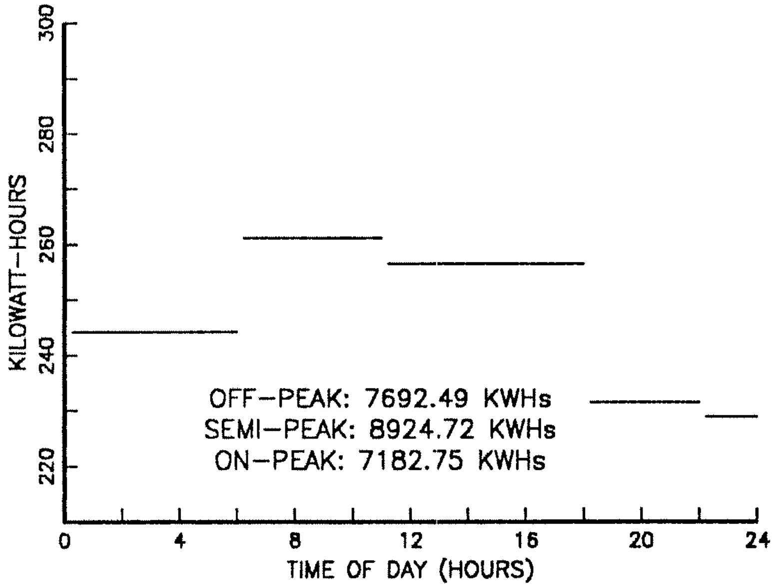

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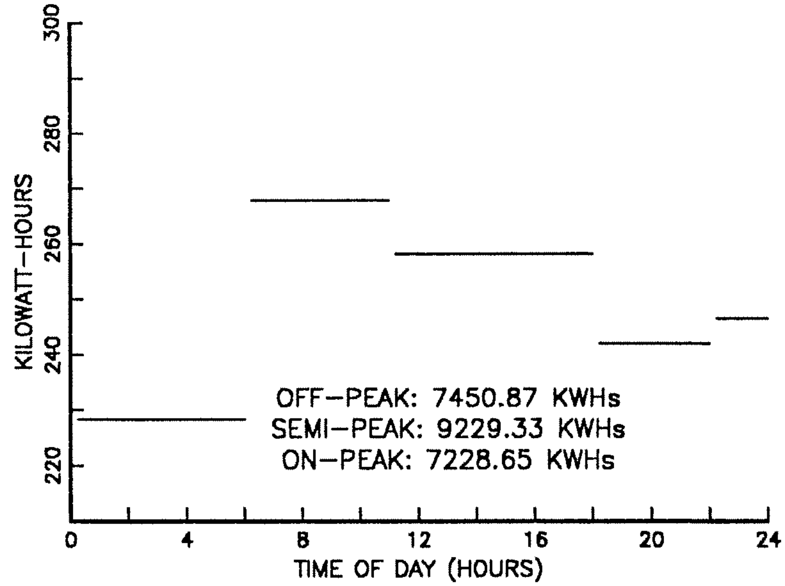

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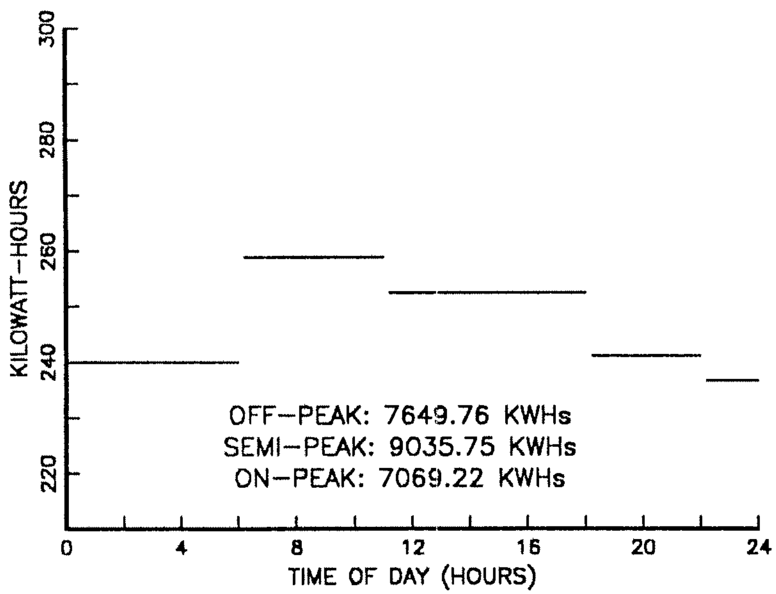

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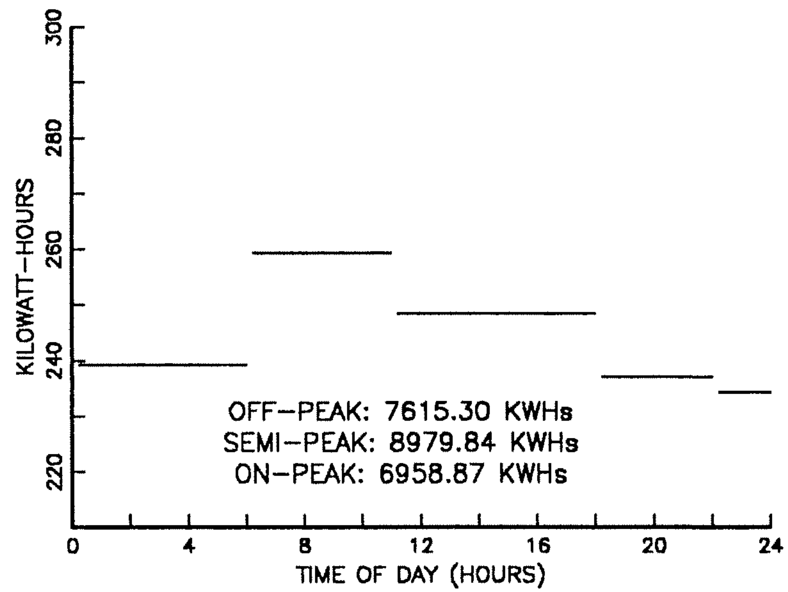

USS LEAHY (CG-16) CONSUMPTION PROFILES

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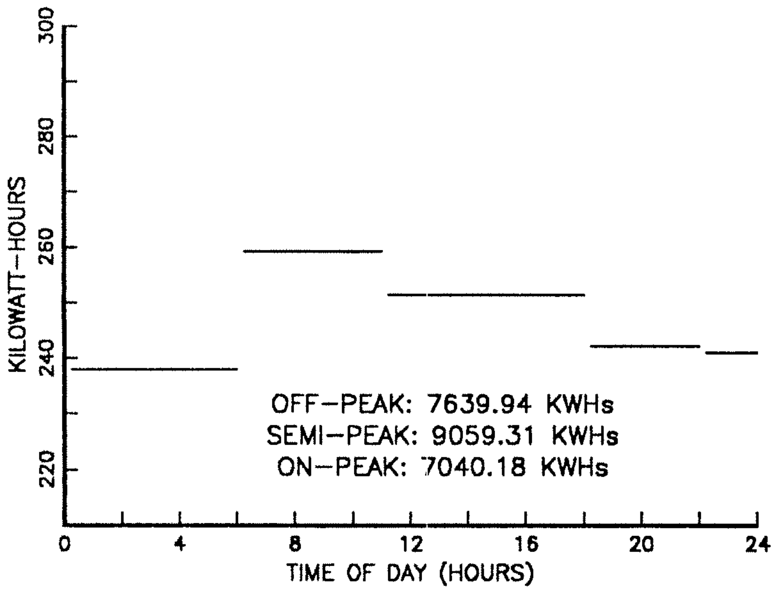

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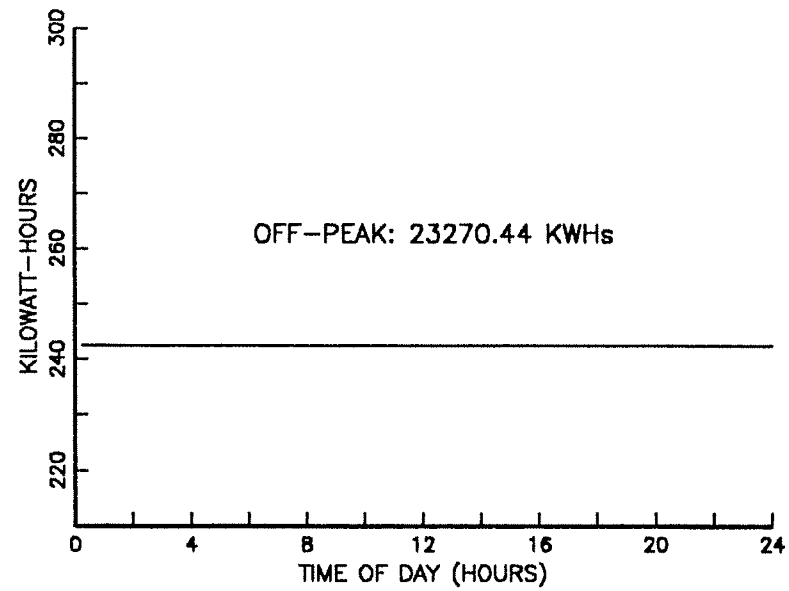

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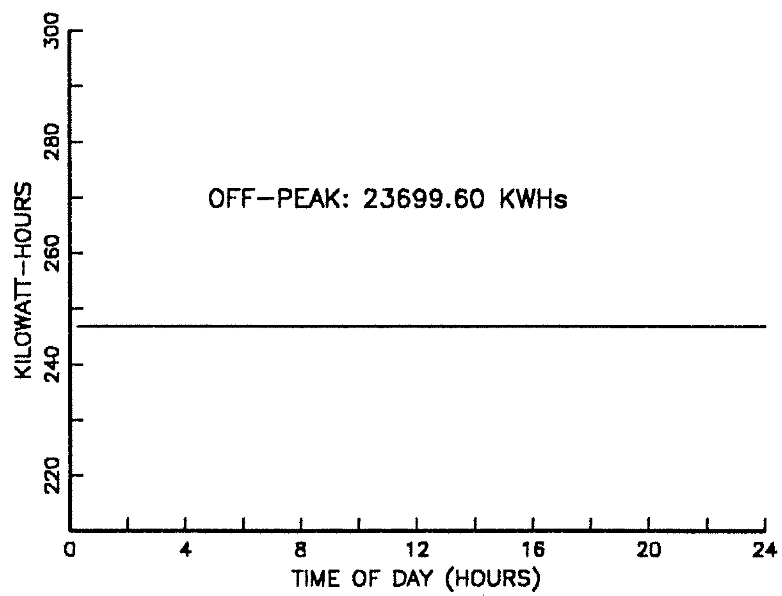

USS DULUTH (LPD-6) CONSUMPTION PROFILES

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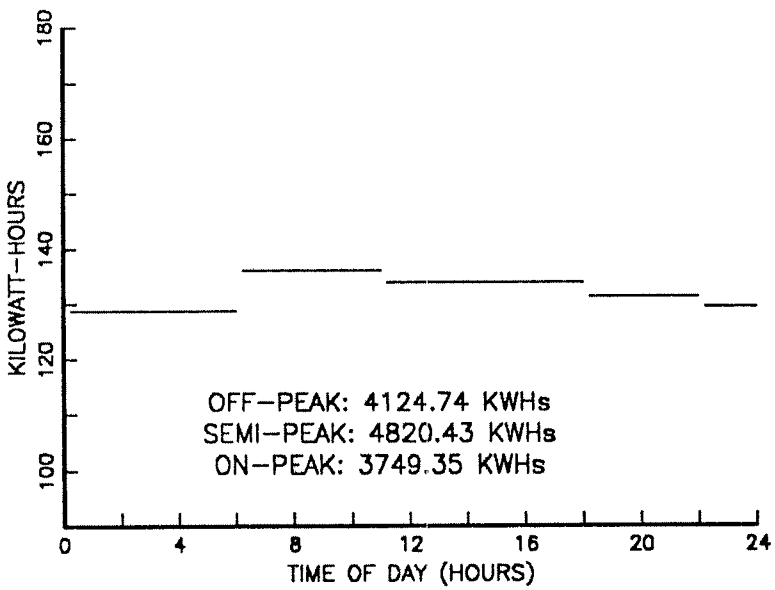

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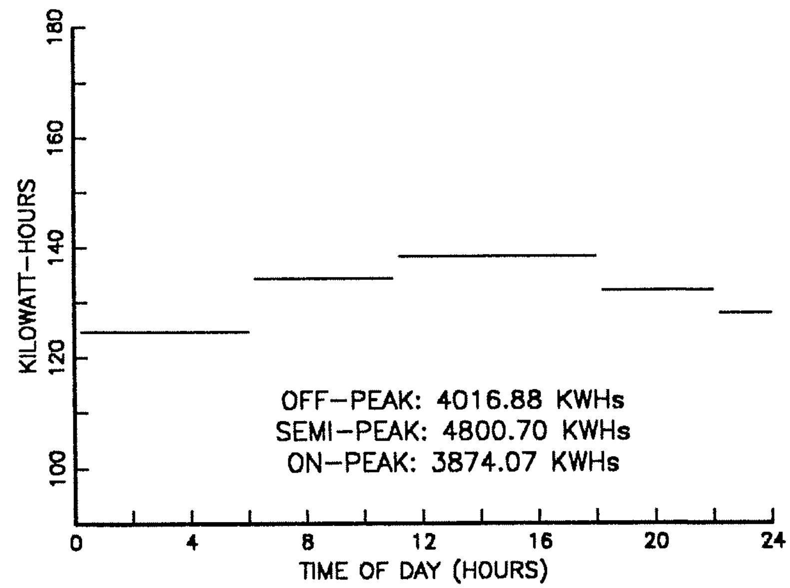

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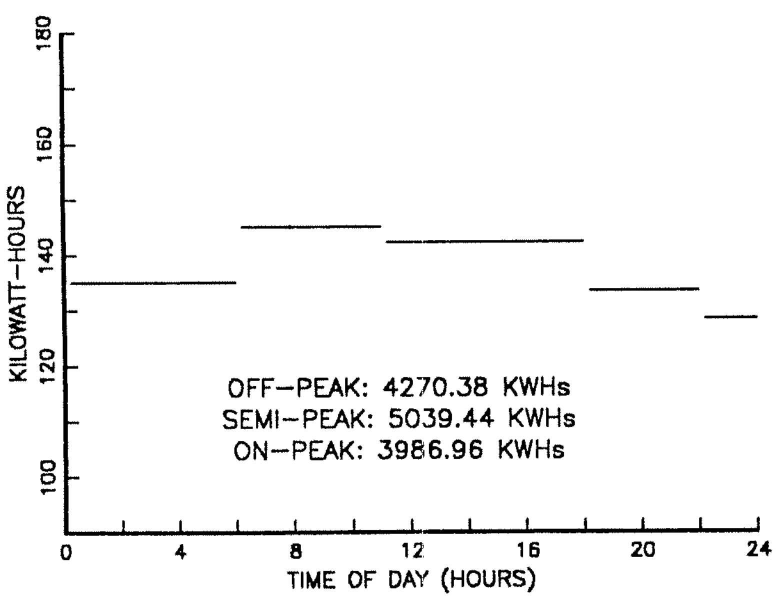

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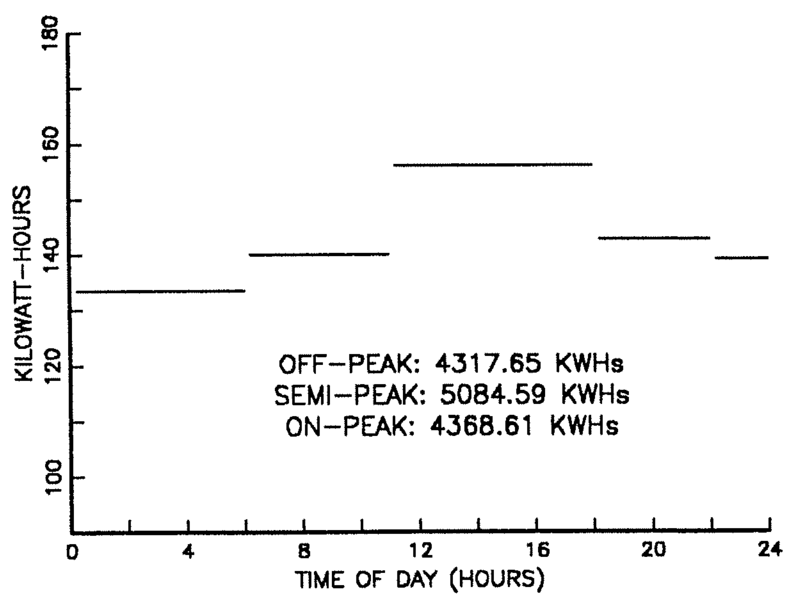

USS DULUTH (LPD-6) CONSUMPTION PROFILES

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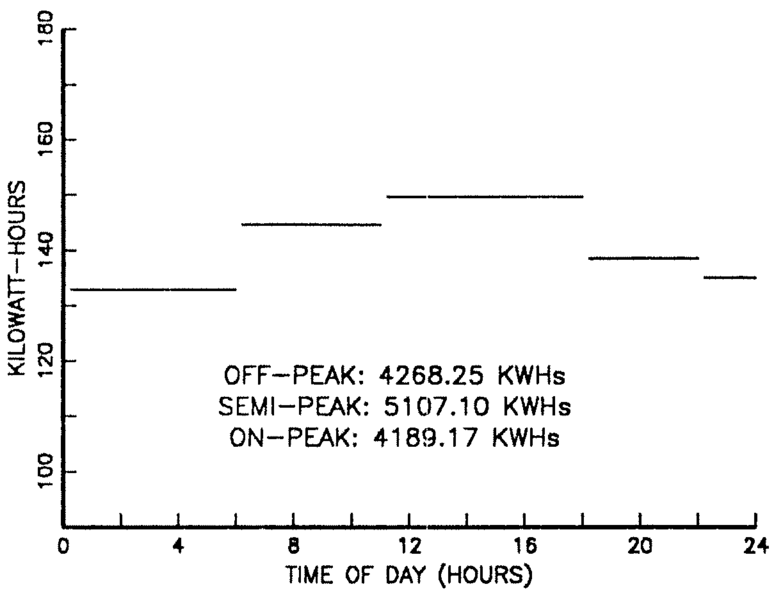

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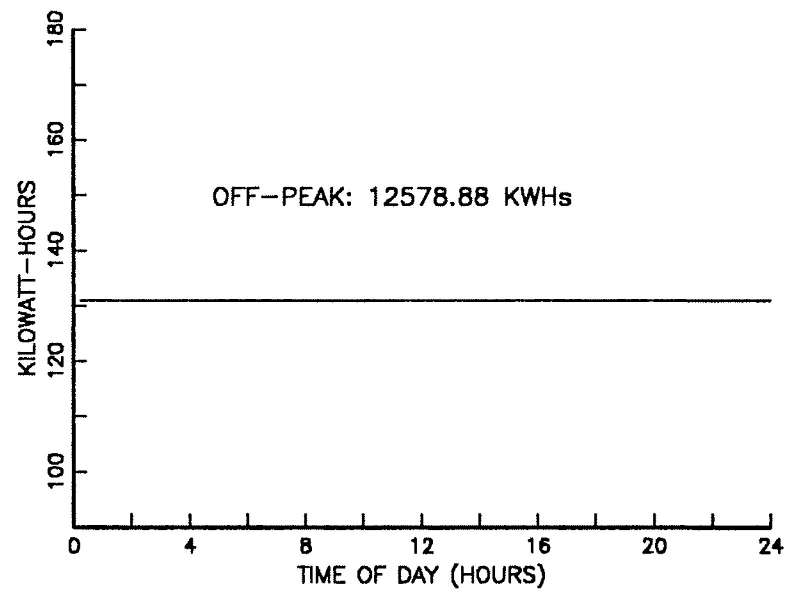

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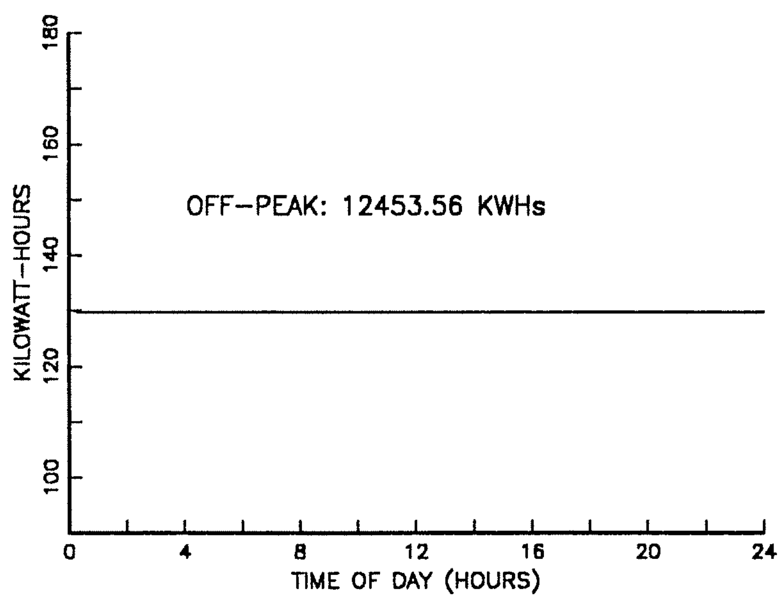

LIST OF REFERENCES

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4. *Monthly Summaries of Local Climatological Data,* National Weather Service Office, San Diego, CA., March & June 1990.

5. Letner, M. and Thomas Bishop, *Experimental Design and Analysis,* Blacksburg, Virginia: Valley, 1986.

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